PowerTCP

Pushing the Performance Limits of Datacenter Networks

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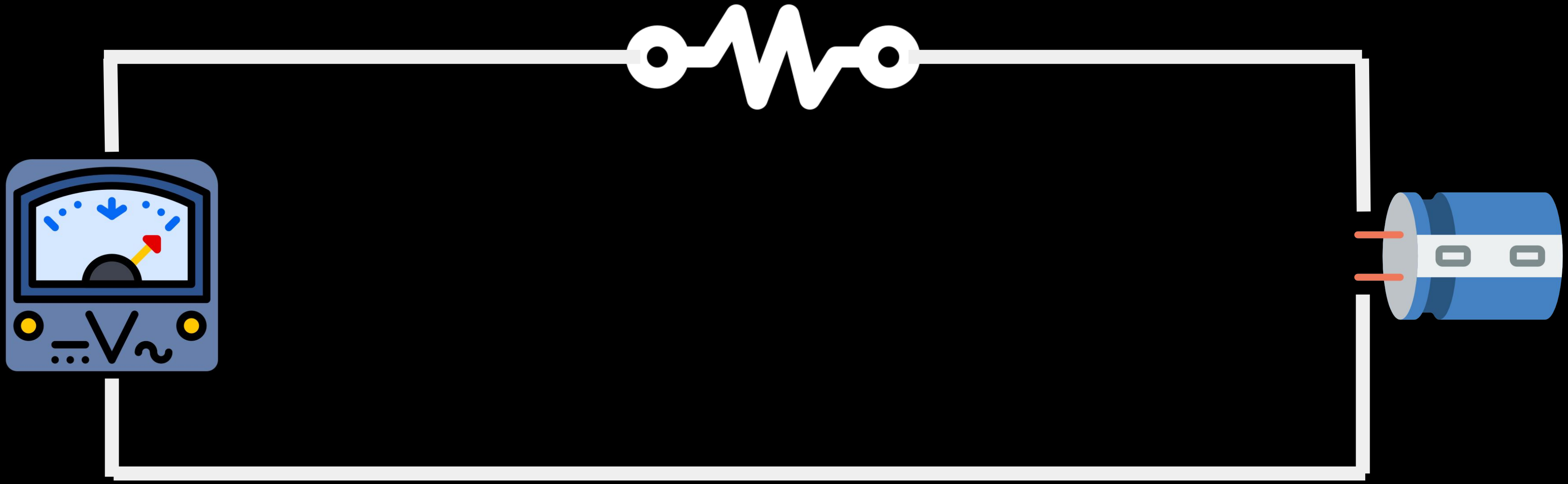
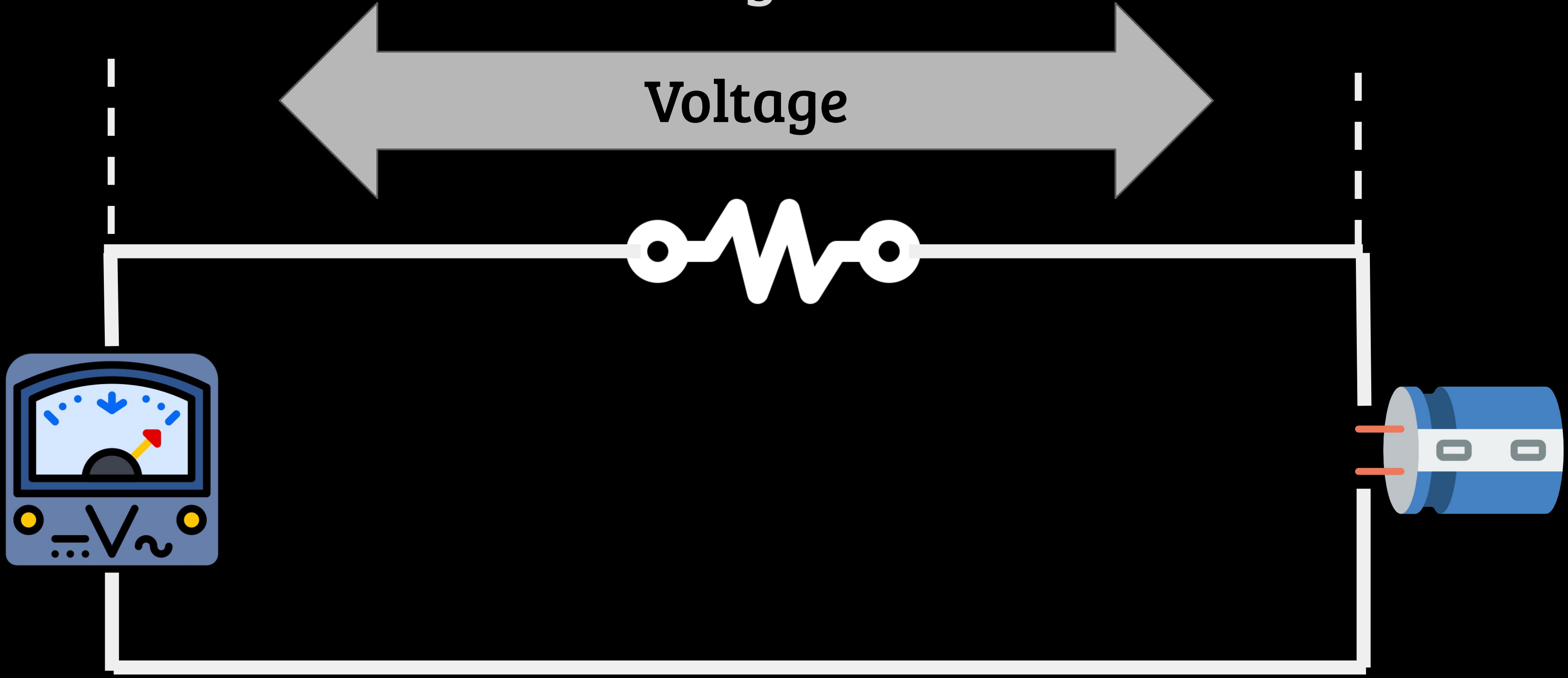
Brief context of electrical systems



Brief context of electrical systems



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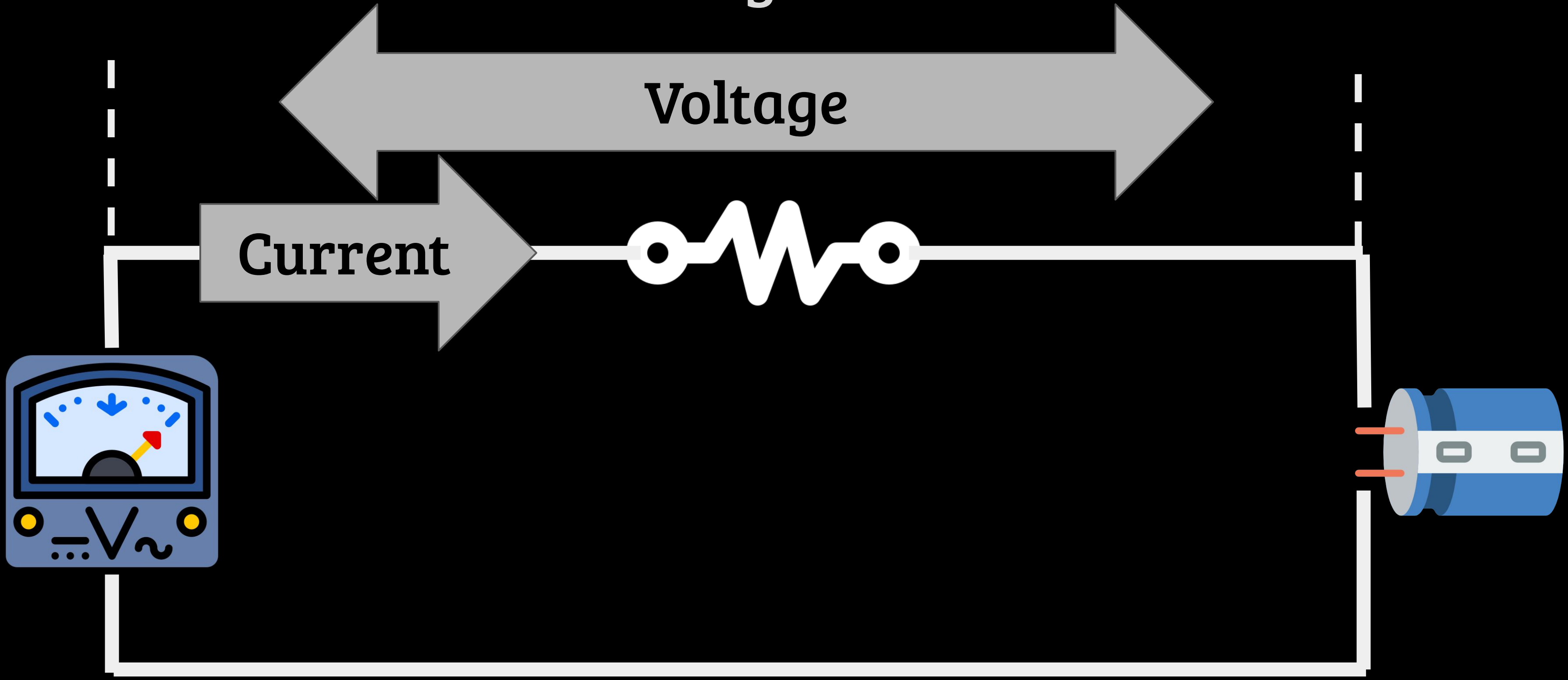

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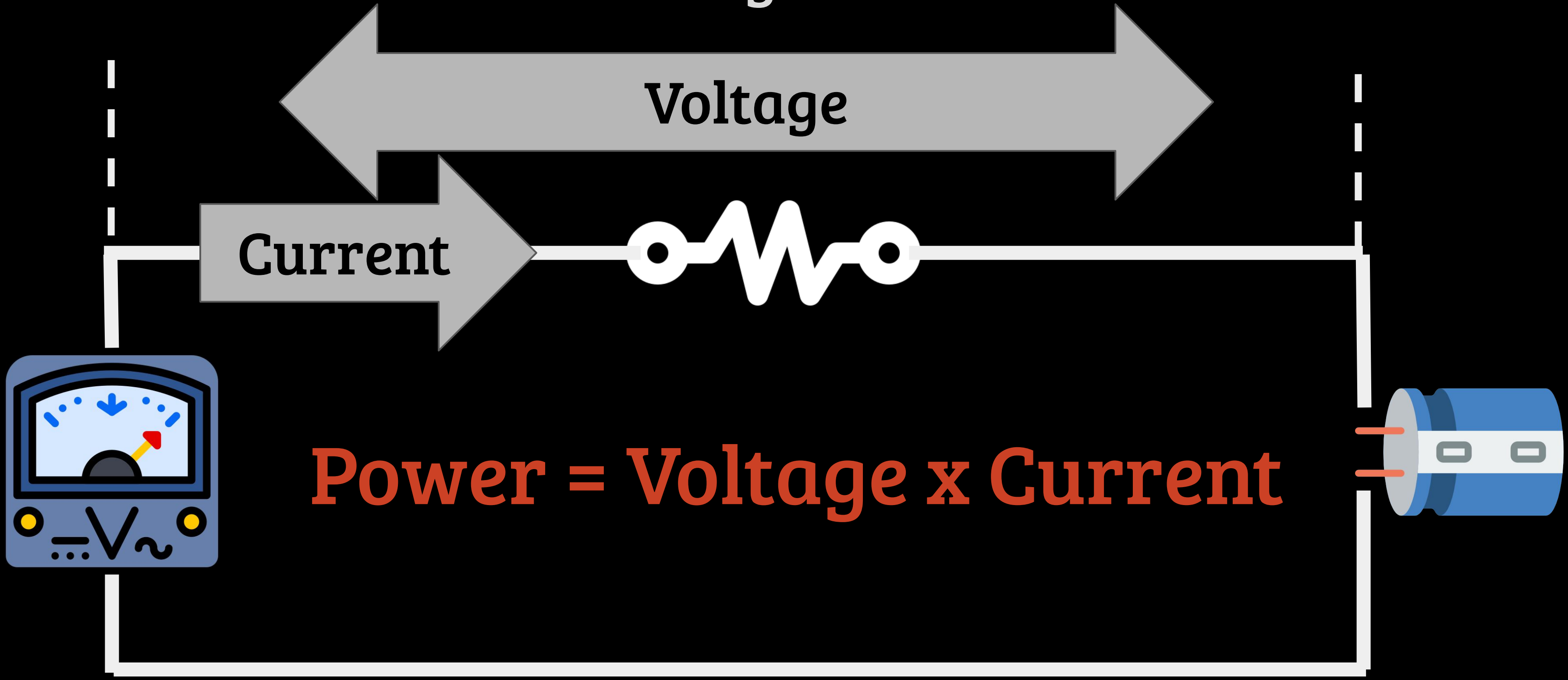
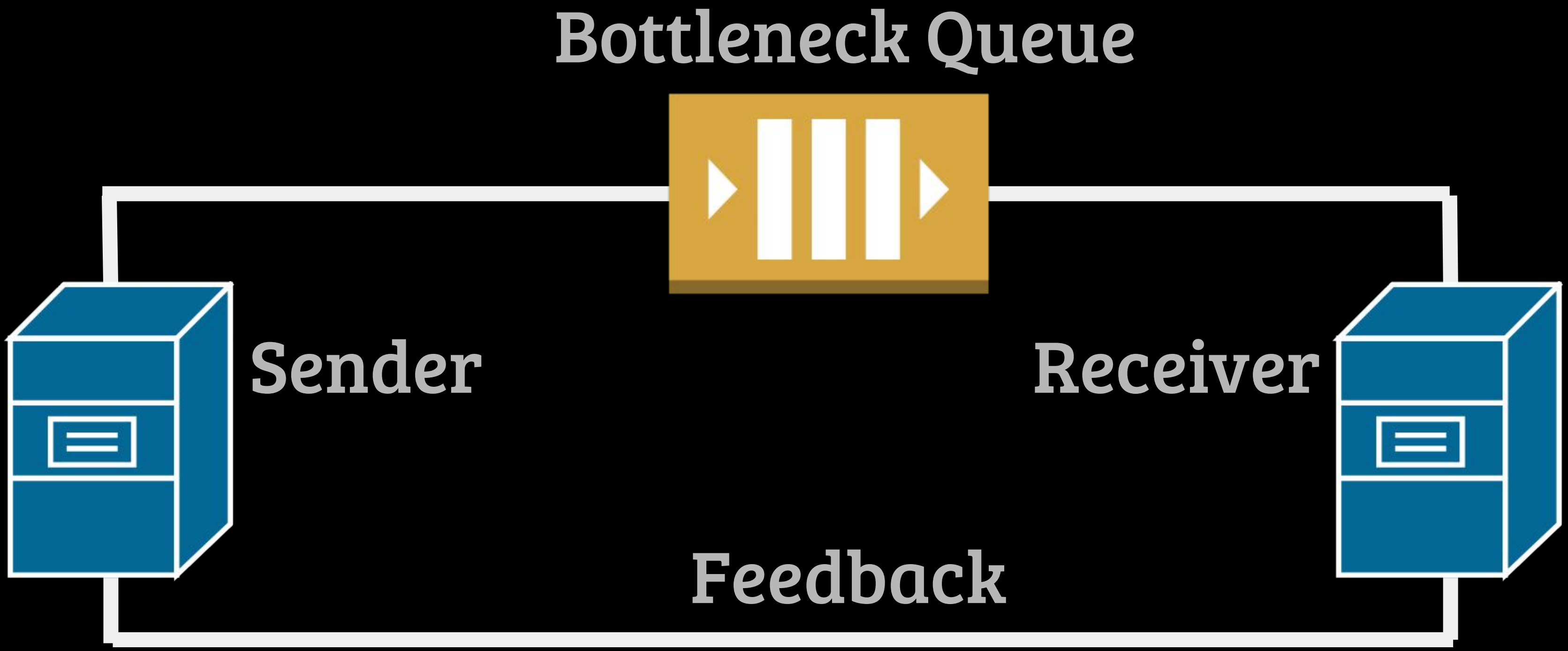


Power = Voltage x Current

Analogy to networked systems



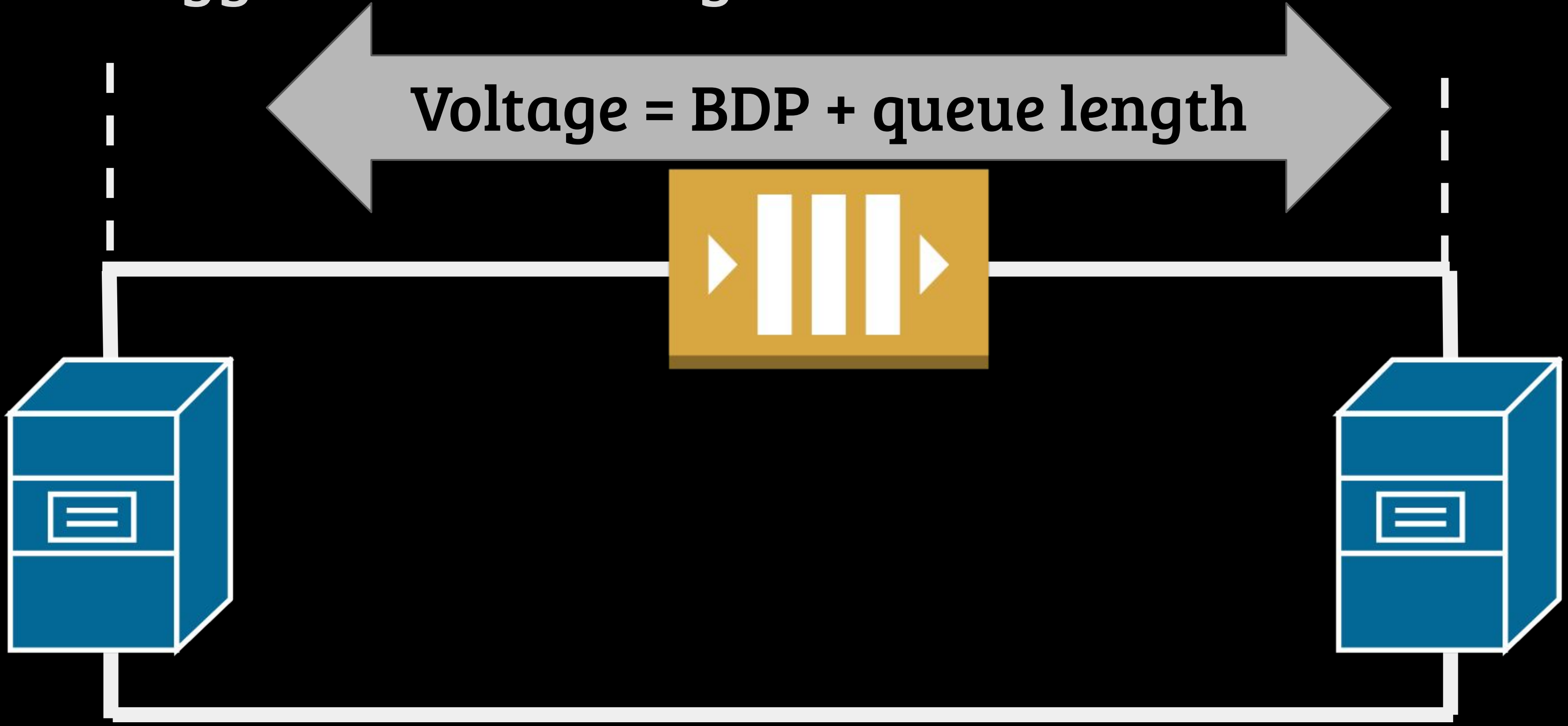
Bottleneck Queue

Sender

Receiver

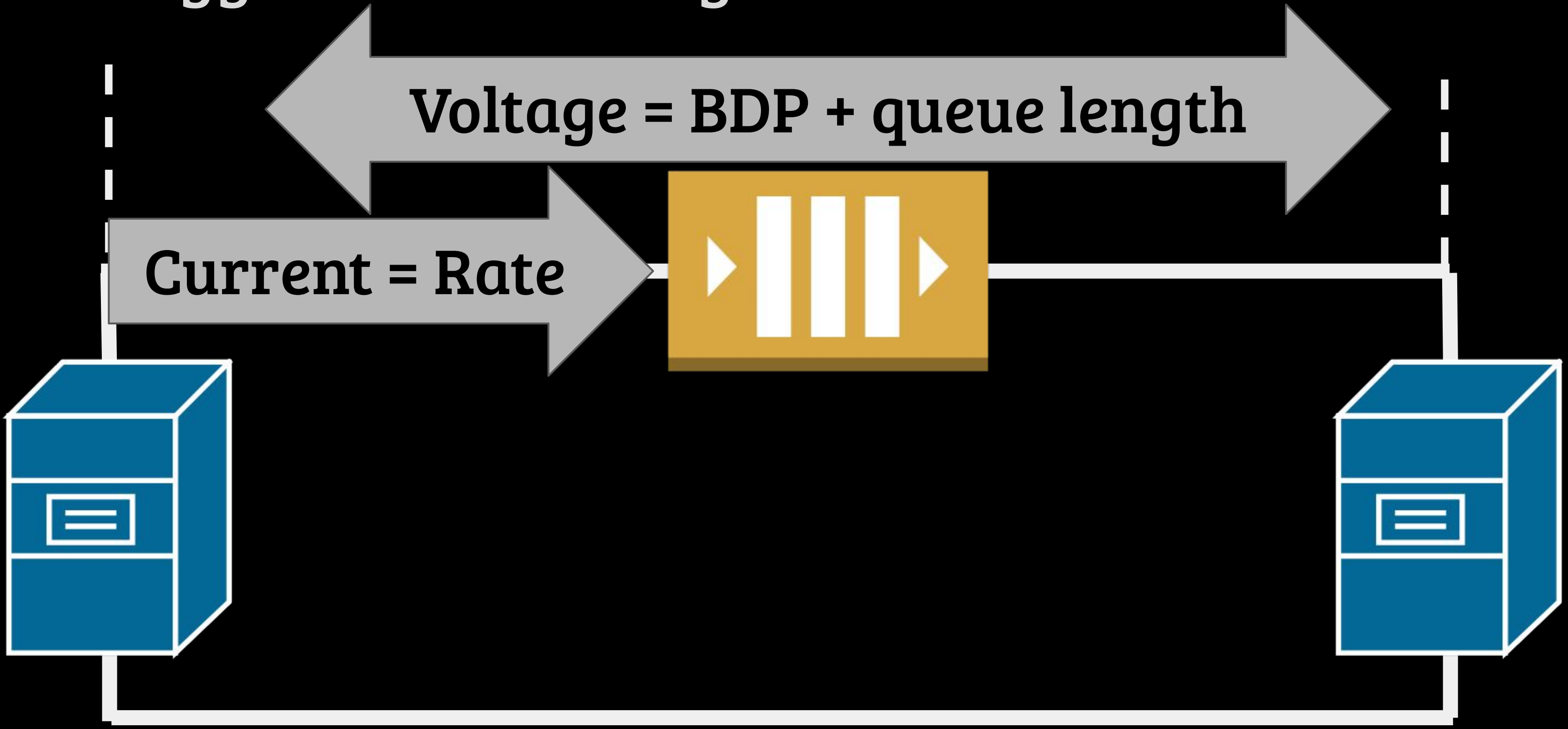
Feedback

Analogy to networked systems



Voltage = BDP + queue length

Analogy to networked systems



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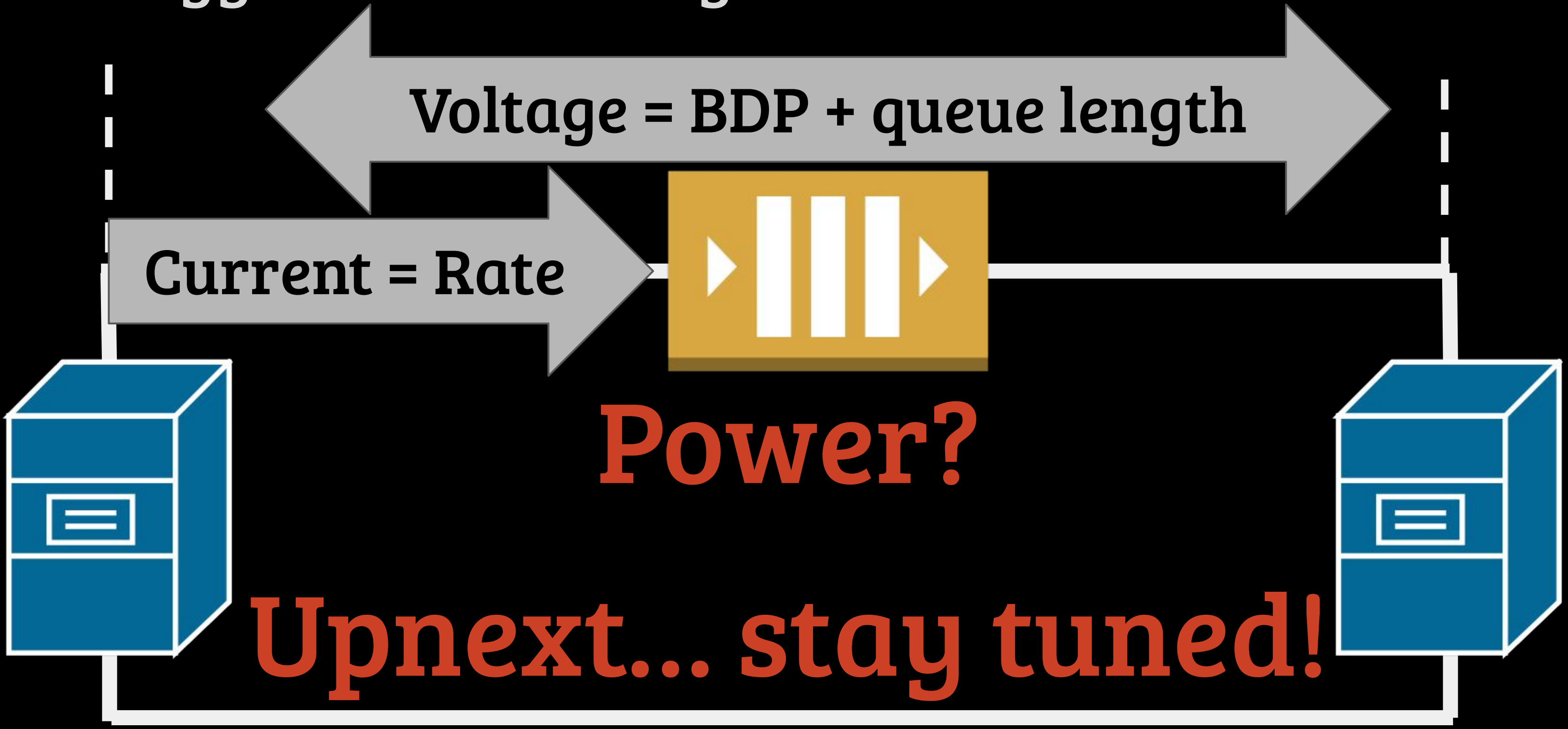


Power?

Upnext… stay tuned!

PowerTCP in a Nutshell

- Power-based congestion control
- Quickly reacts to congestion without losing throughput
- Rapidly converges within 1 RTT
- Fair and asymptotically stable
- Reduces FCTs for short flows by up to 90%

How do we measure Power?

The debate over congestion signals

Microsoft says ECN is better [dctcp]

Google says delay is simple and effective [Timely, Swift]

Alibaba says INT is accurate [HPCC]

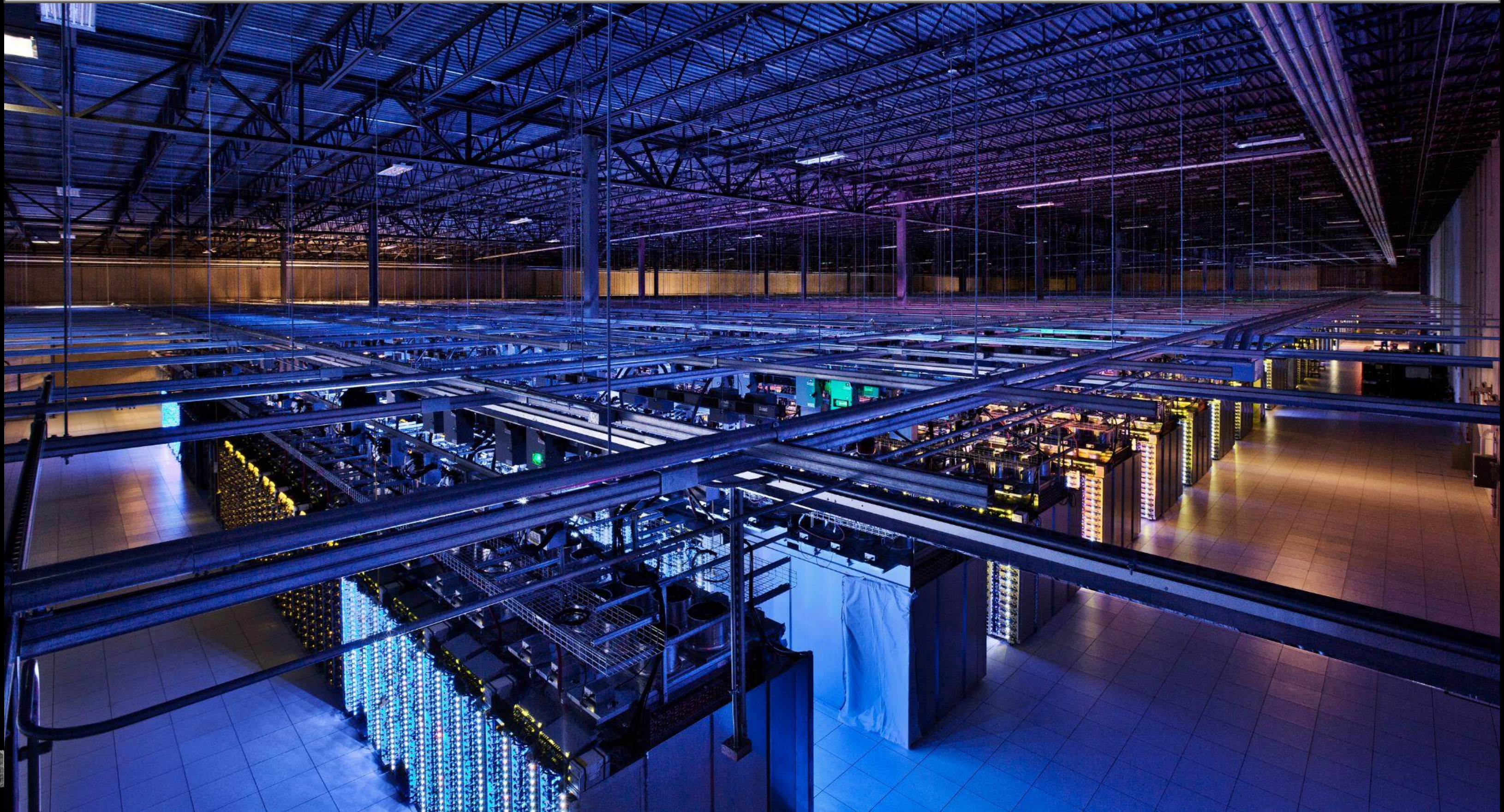
ECN, Delay or INT are essential

What matters more: what we do with it

~~The debate over feedback signals~~

A debate over how to use the feedback

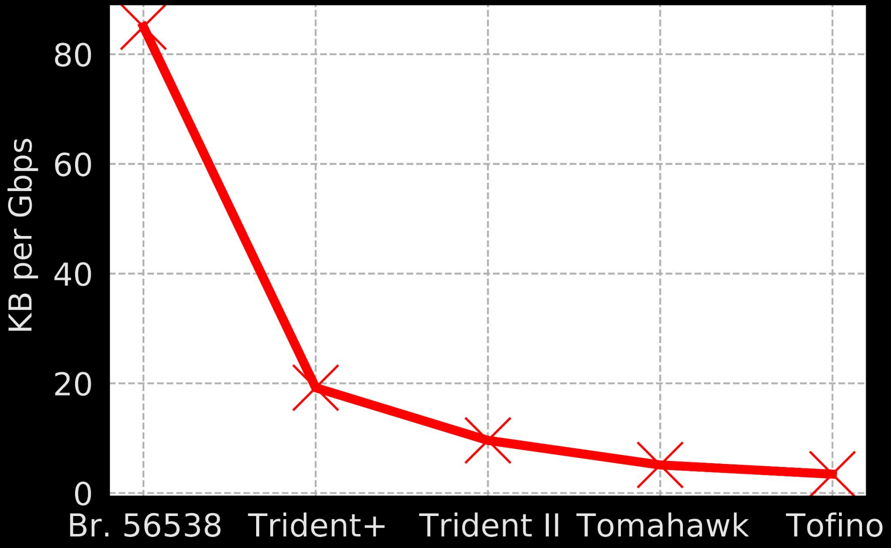
Rare glimpse of Google datacenter



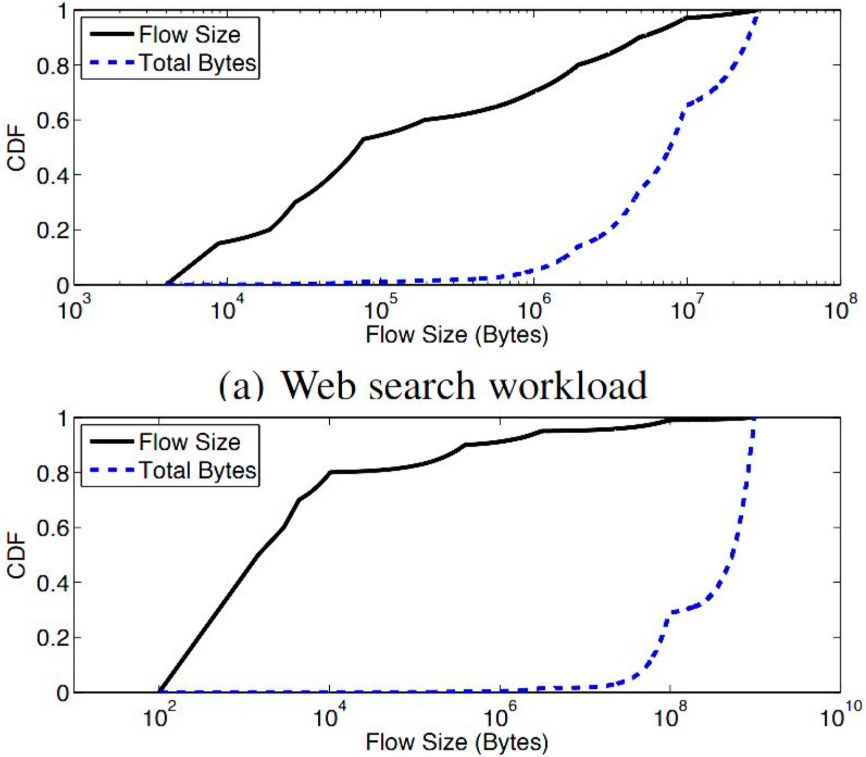
Rare glimpse of Google datacenter

Fear of the buffer

Buffer per unit capacity (KB/Gbps)



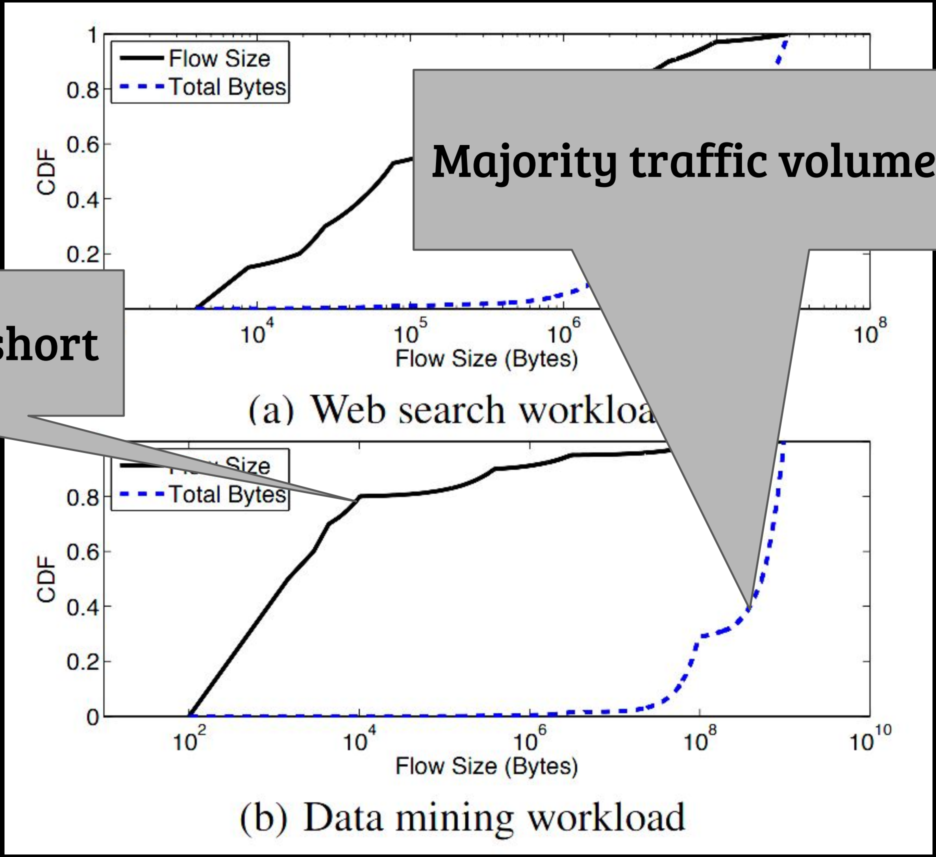
DC workloads and short flows



(a) Web search workload

(b) Data mining workload

DC workloads and short flows



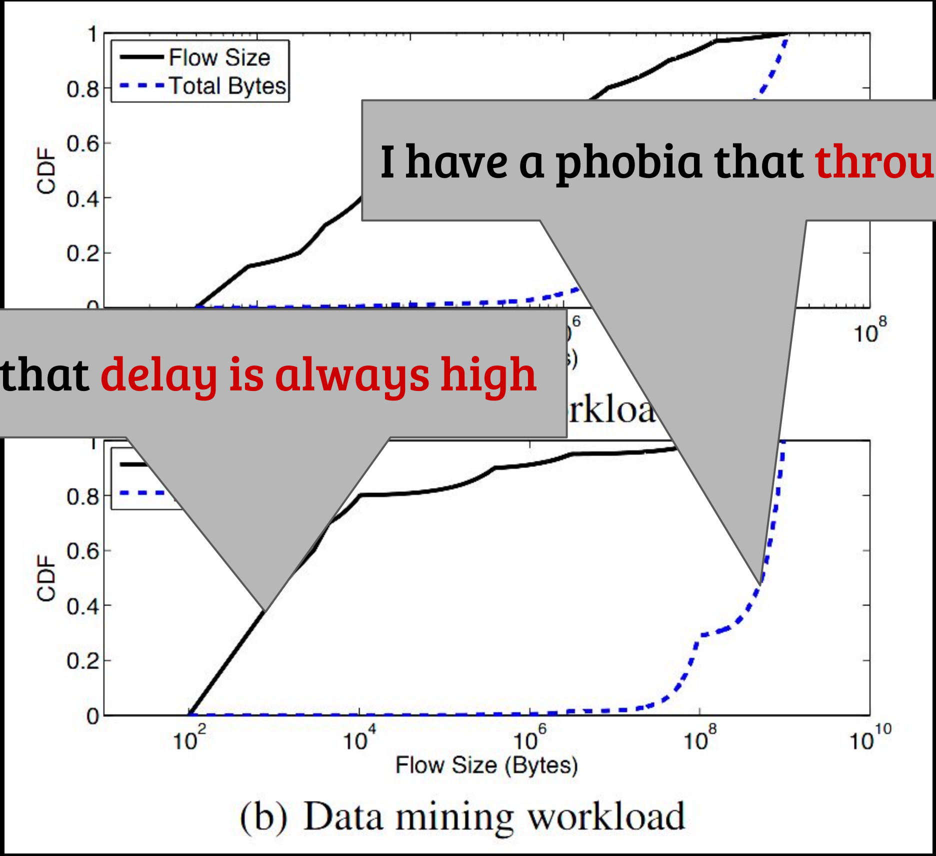
(a) Web search workloa

(b) Data mining workload

Majority traffic volume is from long flows

Majority Flows are short

DC workloads and short flows



(b) Data mining workload

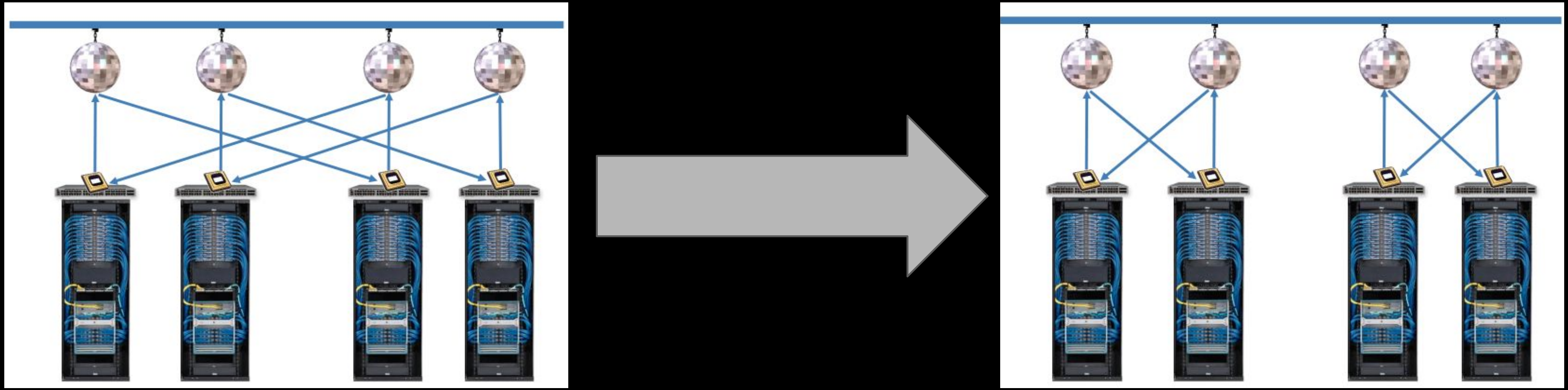
I have a phobia that throughput is always low

I have a constant fear that delay is always high

Emerging technologies and challenges

Not just queueing but quickly utilizing available bandwidth is important too

eg., Emerging Reconfigurable Datacenter Networks (RDCNs)



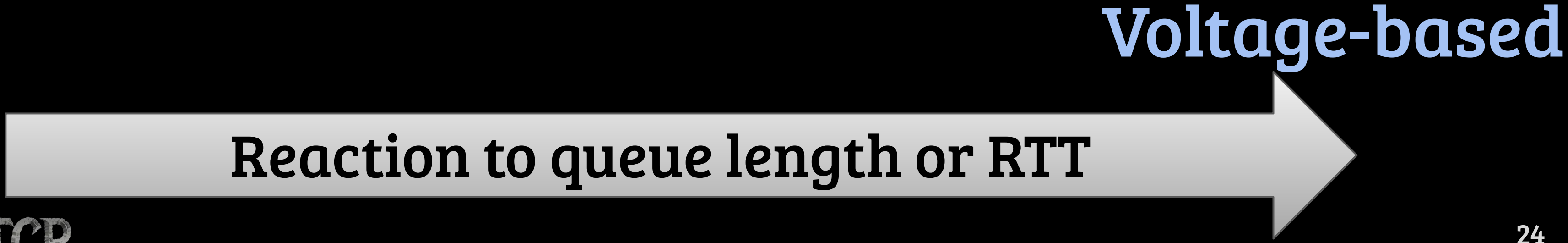
Fine-grained congestion control is important for datacenter performance

Timeline of congestion control in datacenters

- Reno, Cubic
- DCTCP, DCQCN
- Timely
- HPCC
- Swift

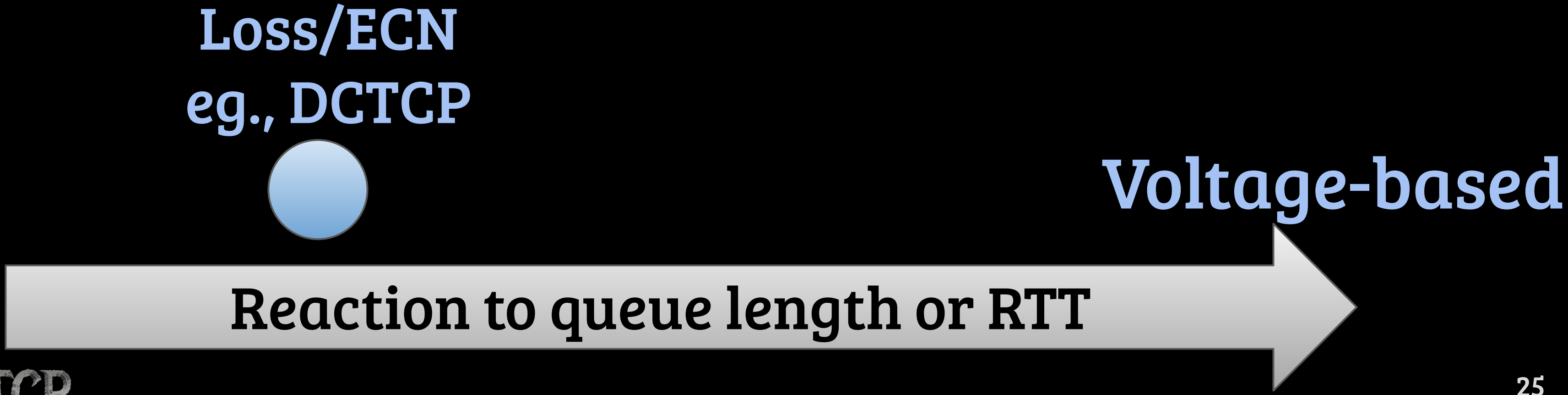
Timeline of congestion control in datacenters

- Voltage-based (BDP + Queue Length)
    - ECN/Loss (eg., DCTCP)
    - RTT based (eg., Swift)
    - Inflight based (eg., HPCC)
- Current-based (Total transmission rate)
    - RTT-gradient based (Eg., Timely)



Voltage-based

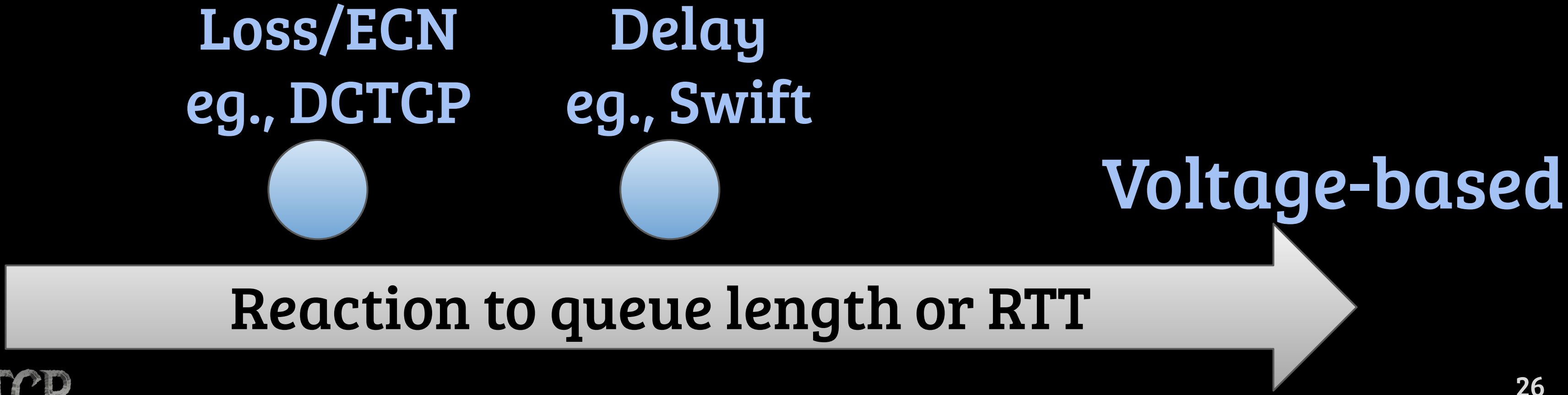
Reaction to queue length or RTT



Loss/ECN
eg., DCTCP

Voltage-based

Reaction to queue length or RTT

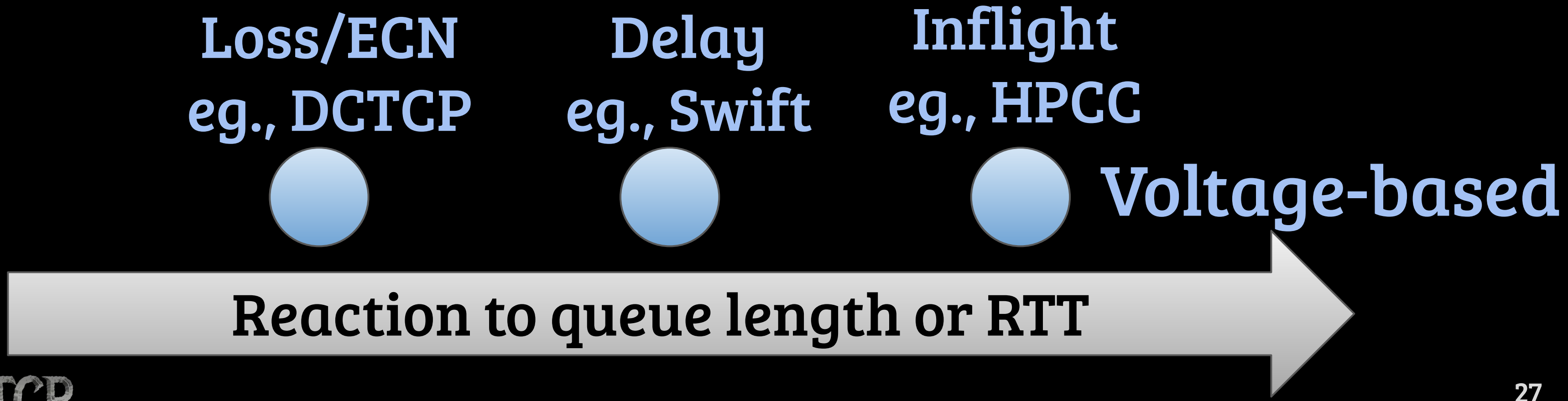


Loss/ECN
eg., DCTCP

Delay
eg., Swift

Voltage-based

Reaction to queue length or RTT



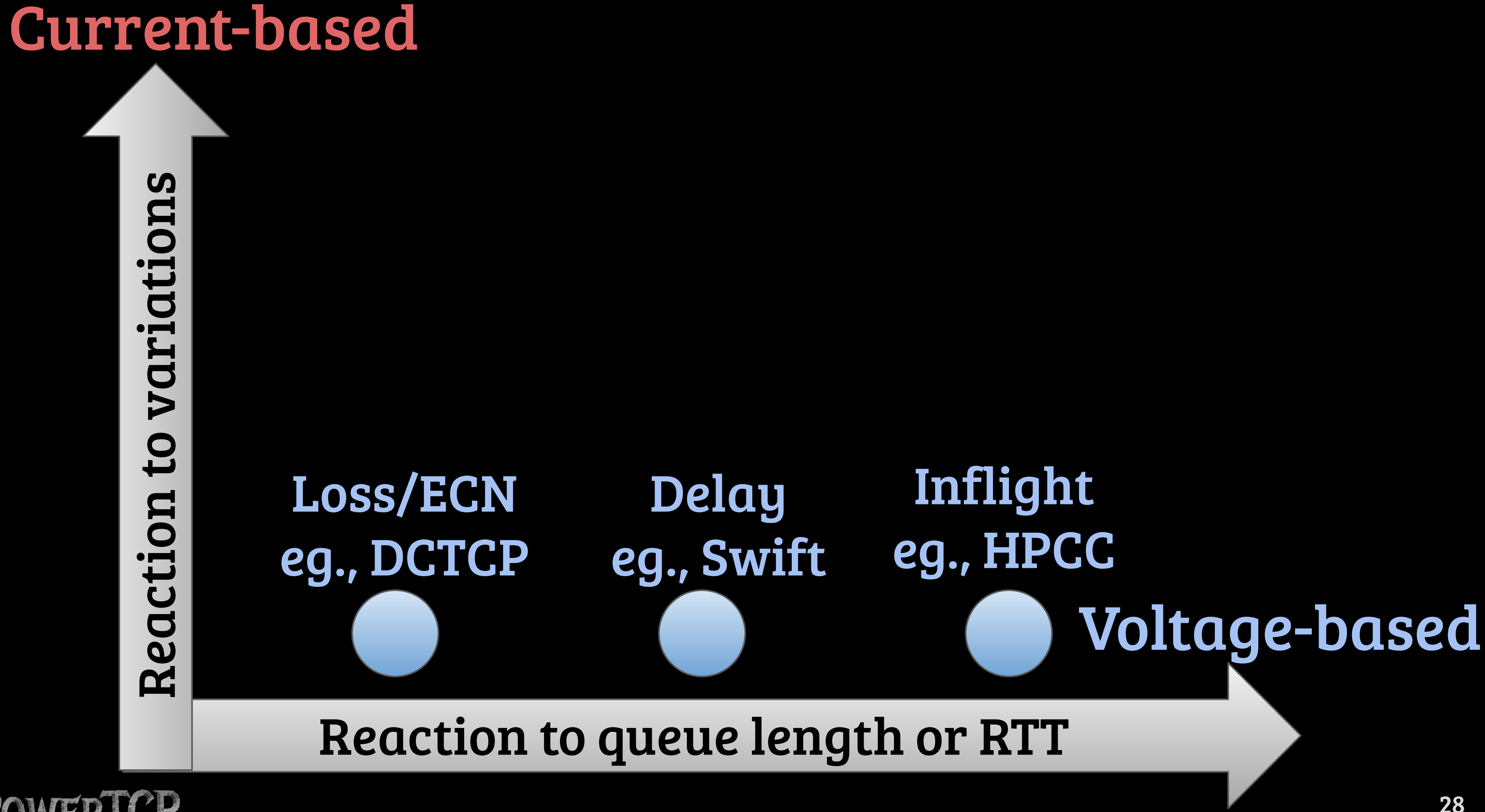
Loss/ECN
eg., DCTCP

Delay
eg., Swift

Inflight
eg., HPCC

Voltage-based

Reaction to queue length or RTT



Current-based

Reaction to variations

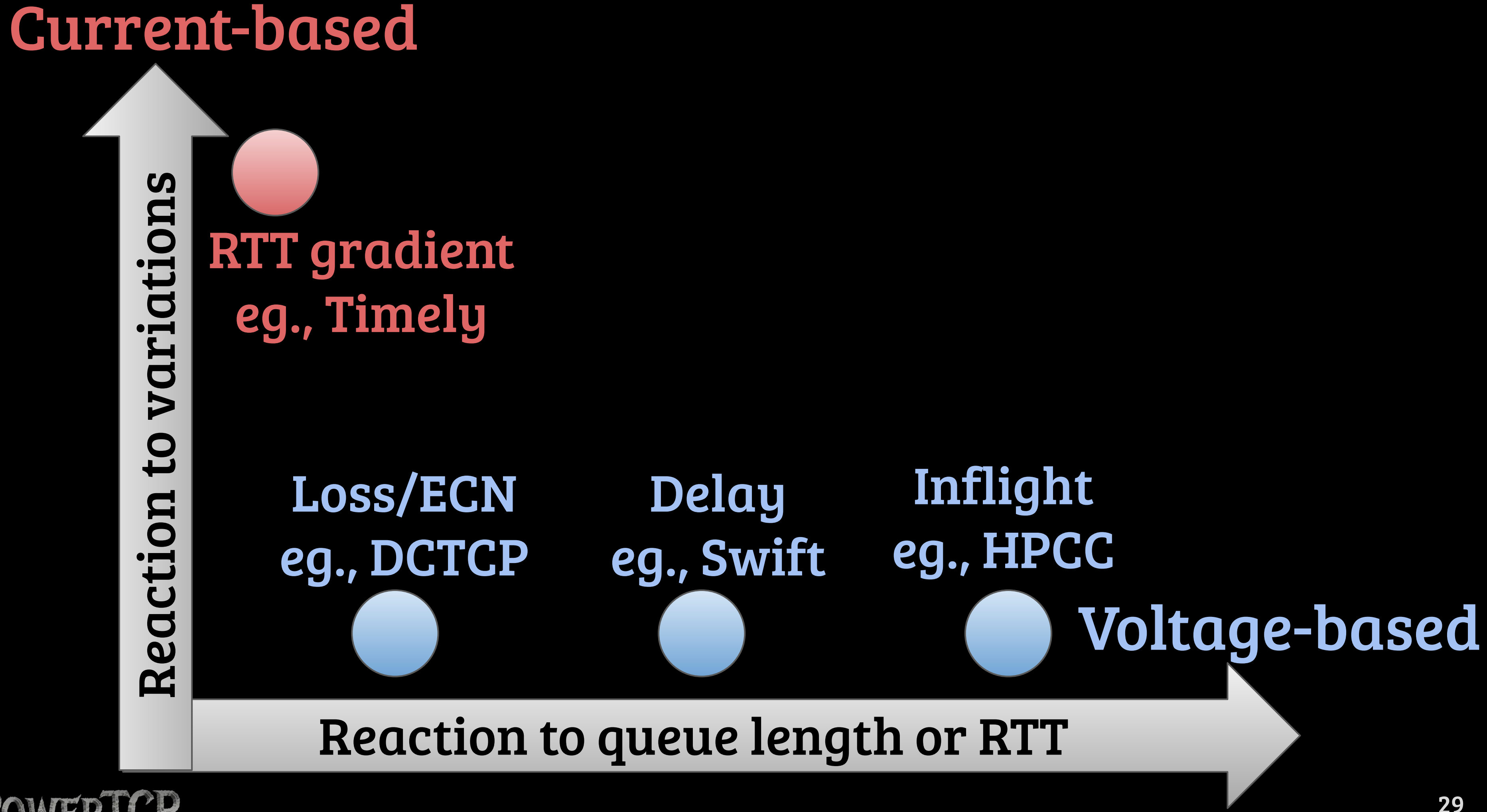
Loss/ECN
eg., DCTCP

Delay
eg., Swift

Inflight
eg., HPCC

Voltage-based

Reaction to queue length or RTT



Current-based

Reaction to variations

RTT gradient
eg., Timely

Loss/ECN
eg., DCTCP

Delay
eg., Swift

Inflight
eg., HPCC

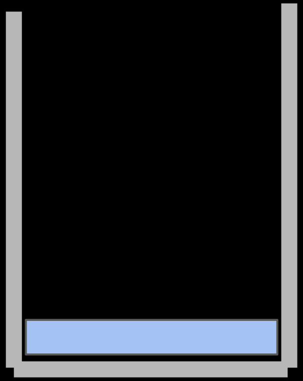
Voltage-based

Reaction to queue length or RTT

Problems of existing approaches

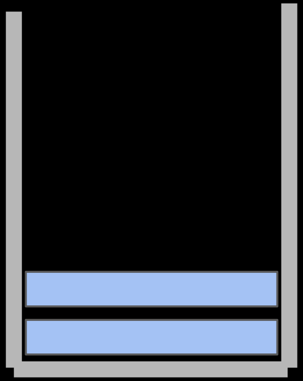
Fundamentally limited to a single dimension

Problems of existing approaches



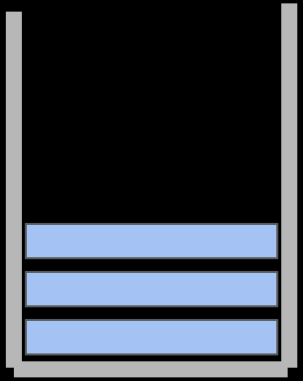
5 Packets

Problems of existing approaches



10 Packets

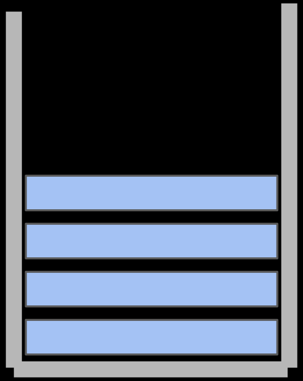
Problems of existing approaches



15 Packets

PowerTCP

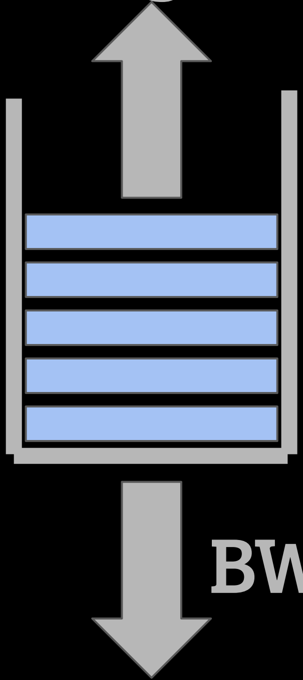
Problems of existing approaches



20 Packets

Problems of existing approaches

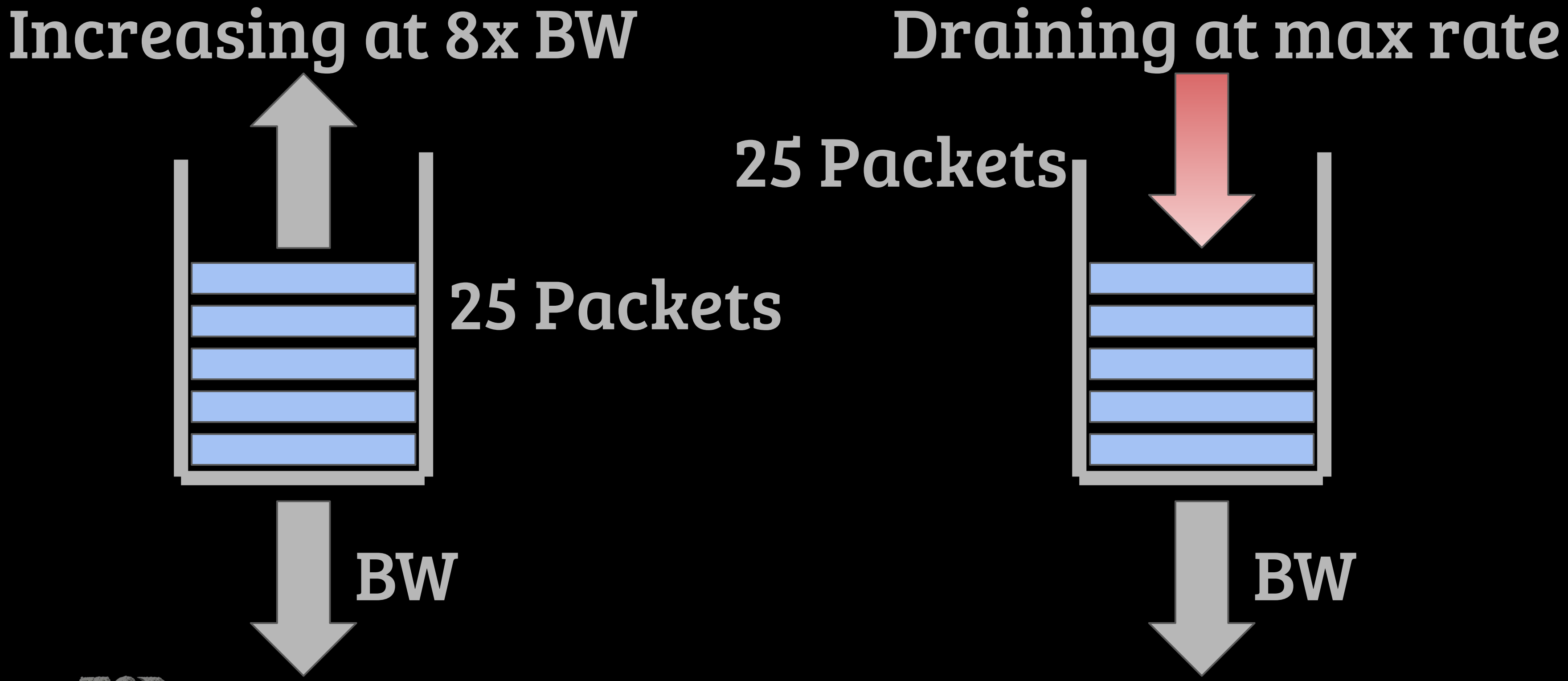
Increasing at 8 x BW



25 Packets

BW

Problems of existing approaches



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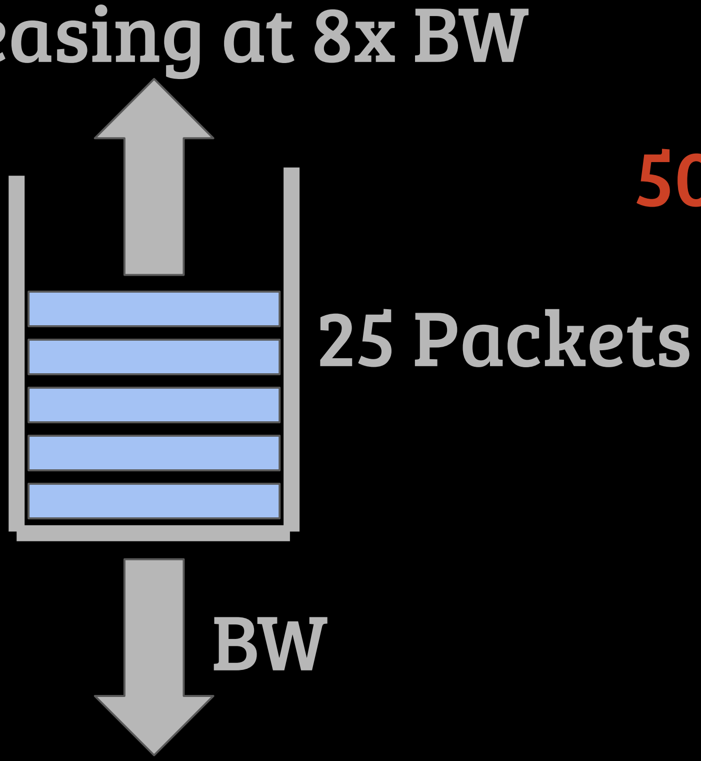
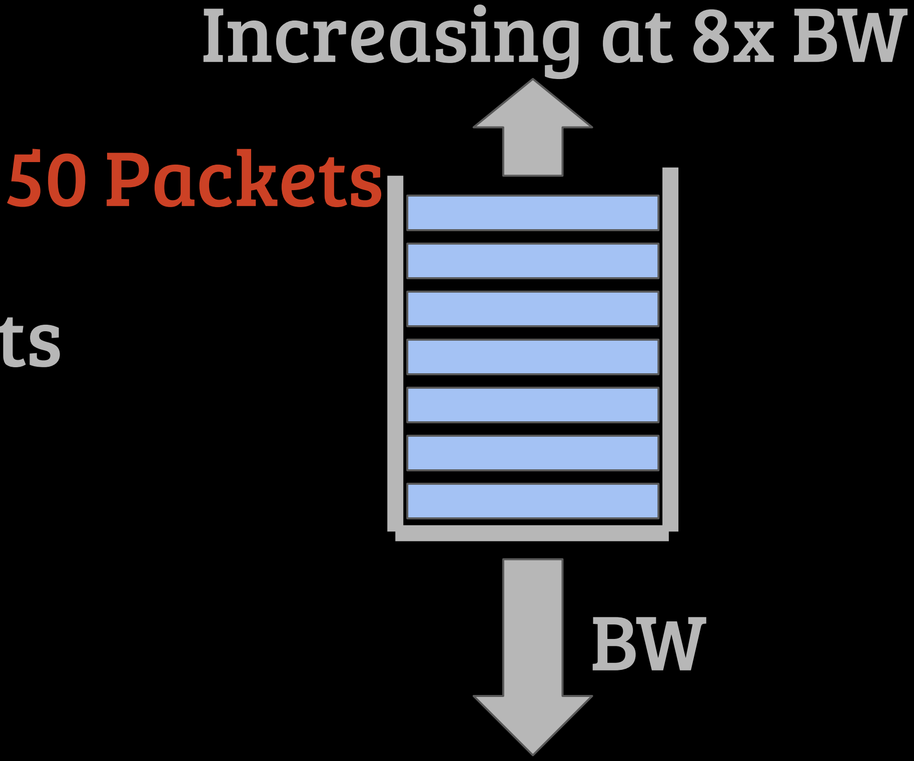

Increasing at 8x BW

25 Packets

BW

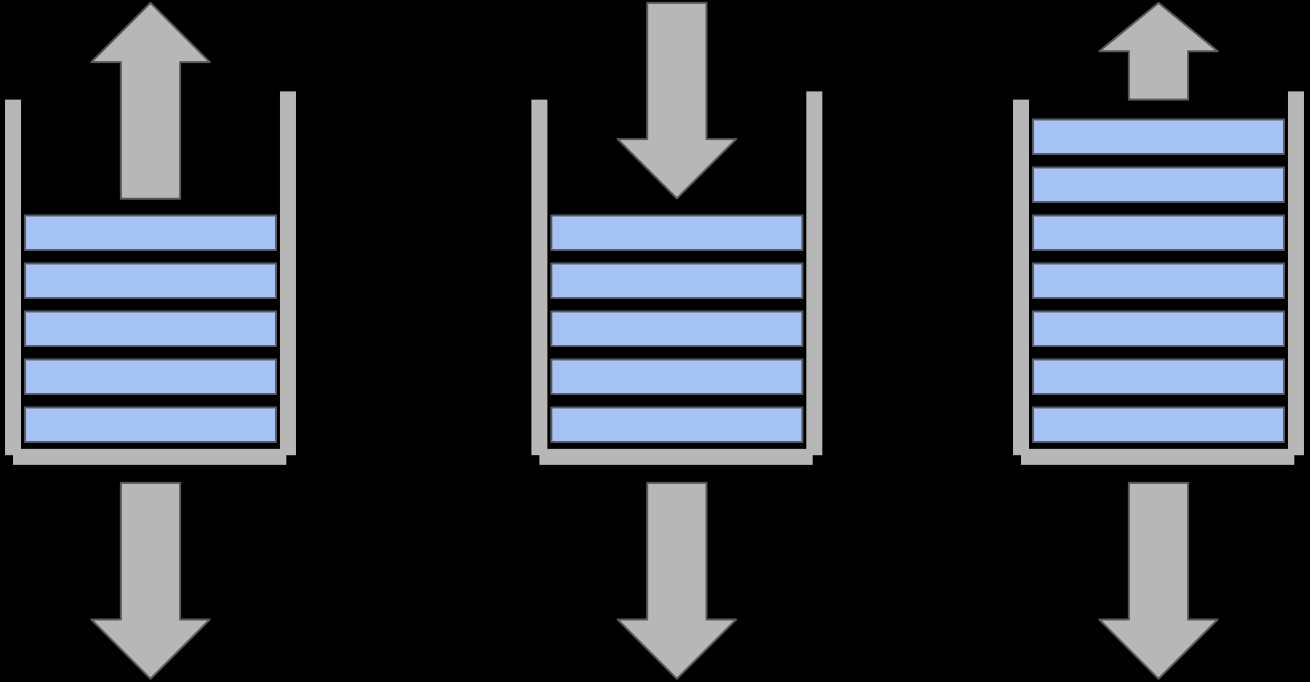

Increasing at 8x BW

50 Packets

BW

Problems of existing approaches

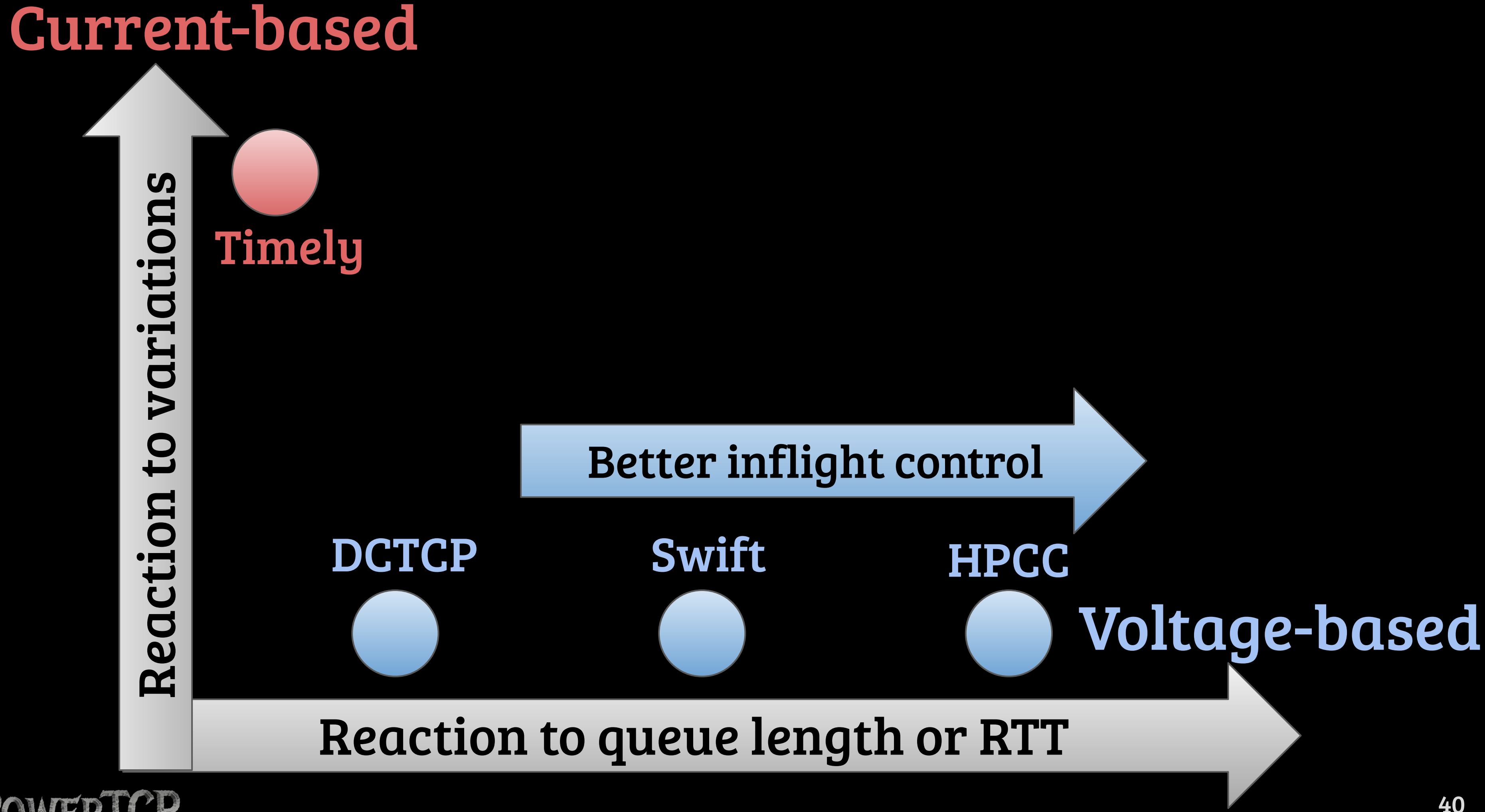
Fundamentally limited to a single dimension



POWERTCP

Summary of Our Analysis

- Voltage-based
  - Can in-principle achieve near-zero queue equilibrium
  - Slow reaction
- Current-based
  - Unstable with no equilibrium
  - Fast Reaction



Current-based

Timely

Reaction to variations

Better inflight control

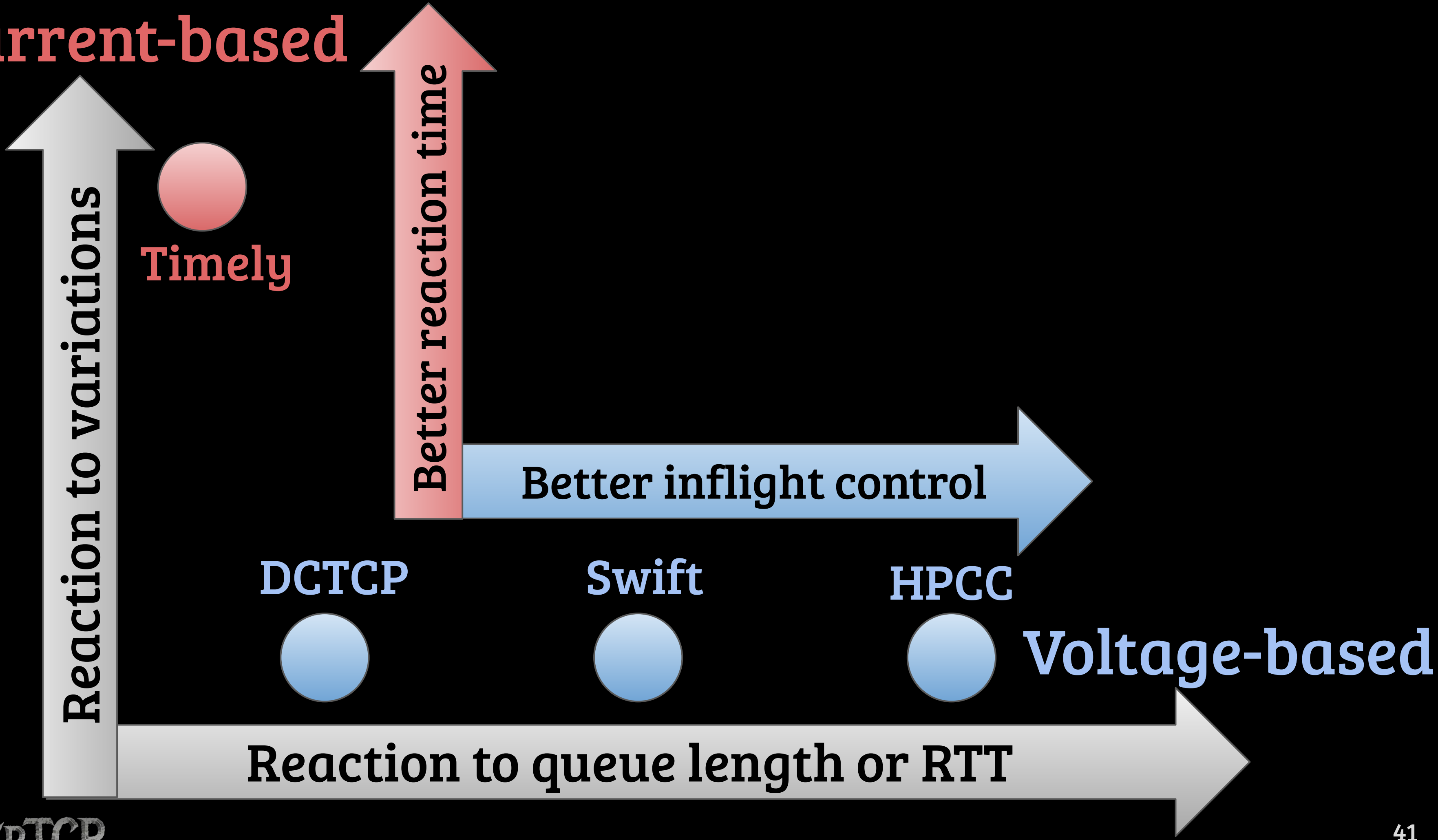
DCTCP

Swift

HPCC

Voltage-based

Reaction to queue length or RTT



Current-based

Timely

Reaction to variations

Better reaction time

Better inflight control

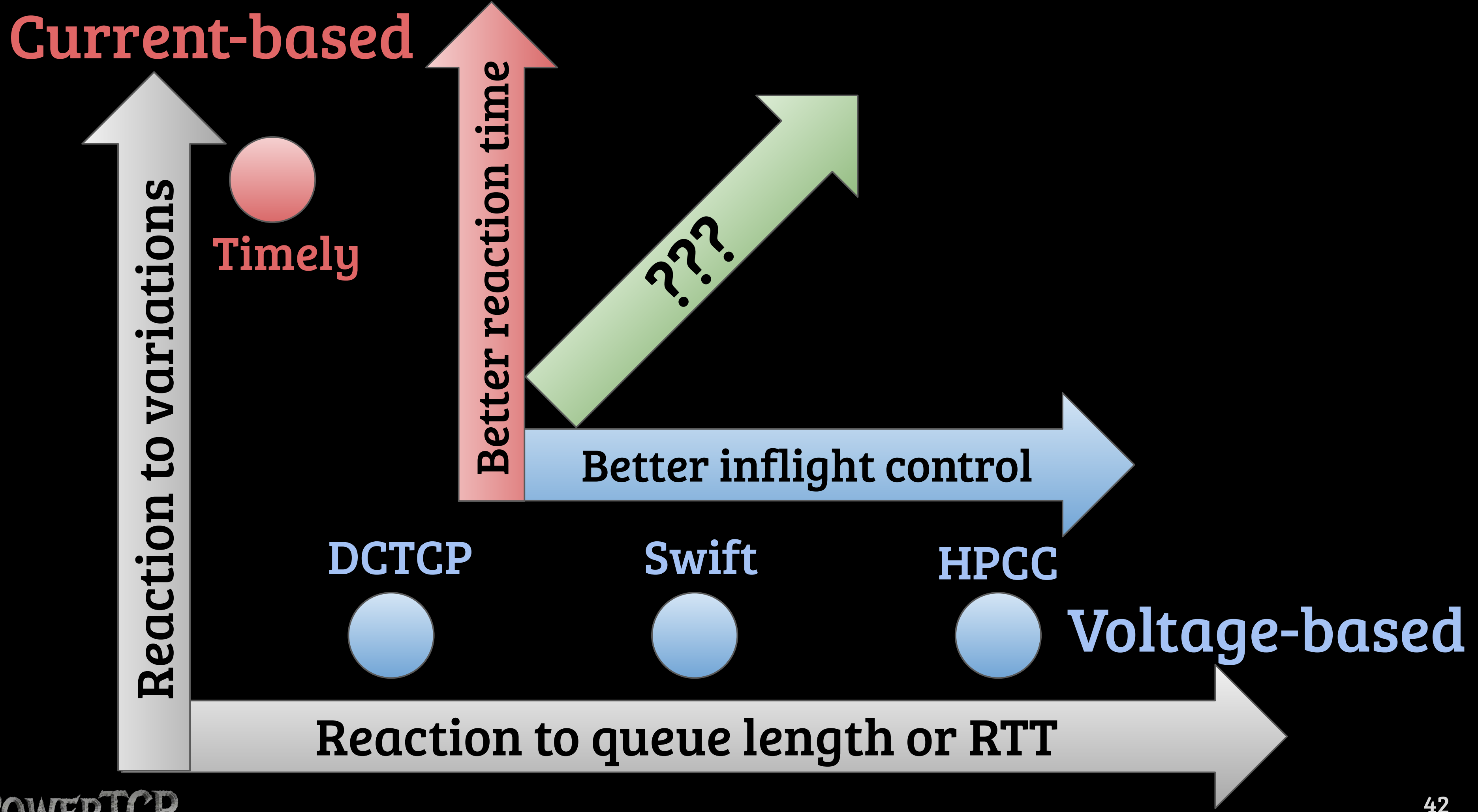
DCTCP

Swift

HPCC

Voltage-based

Reaction to queue length or RTT


Current-based
Timely
Better reaction time
???
Better inflight control
Reaction to variations
DCTCP
Swift
HPCC
Voltage-based
Reaction to queue length or RTT

POWERTCP

The notion of power

Power = Voltage x Current

$$\underbrace{\Gamma}_{\text{Power}} = \underbrace{\left(q(t) + b \times \tau\right)}_{\substack{\text{Voltage} \\ \big\downarrow \\ \text{BDP+queue bytes}}} \times \underbrace{\left(\dot{q}(t) + \mu(t)\right)}_{\substack{\text{Current} \\ \big\downarrow \\ \text{Total rate}}}$$

The notion of power

Enqueue rate = queue-gradient + Dequeue rate

$$\lambda(t - t^f) = \dot{q}(t) + \mu(t)$$

Sending rate = Window per RTT

$$\lambda(t) = \frac{w(t)}{\theta(t)}$$

RTT = queueing delay + base RTT

$$\theta(t - t^f) = \frac{q(t)}{b} + \tau$$

The notion of power

$$b \times w(t - t^f) = \underbrace{(q(t) + b \times \tau)}_{\text{Voltage}} \times \underbrace{(\dot{q}(t) + \mu(t))}_{\text{Current}}$$

The notion of power

A function of both queue length and variations

The notion of power

A function of both queue length and variations

- Detects increased queue lengths

The notion of power

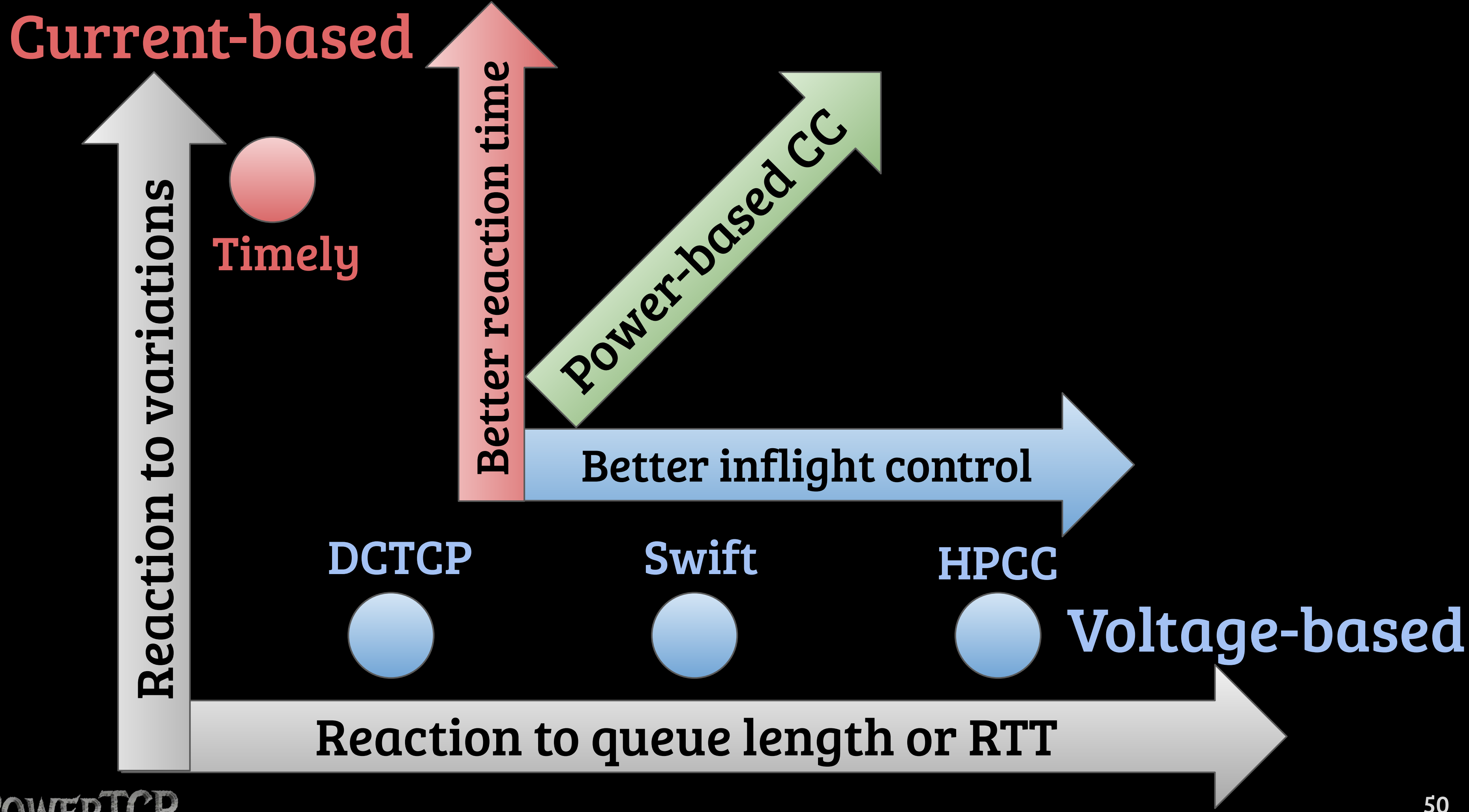
A function of both queue length and variations

- Detects increased queue lengths
- Detects congestion onset and intensity

The notion of power

A function of both queue length and variations

- Detects increased queue lengths
- Detects congestion onset and intensity
- Detects rapid drop in queue lengths



Current-based

Reaction to variations

Timely

Better reaction time

Power-based CC

Better inflight control

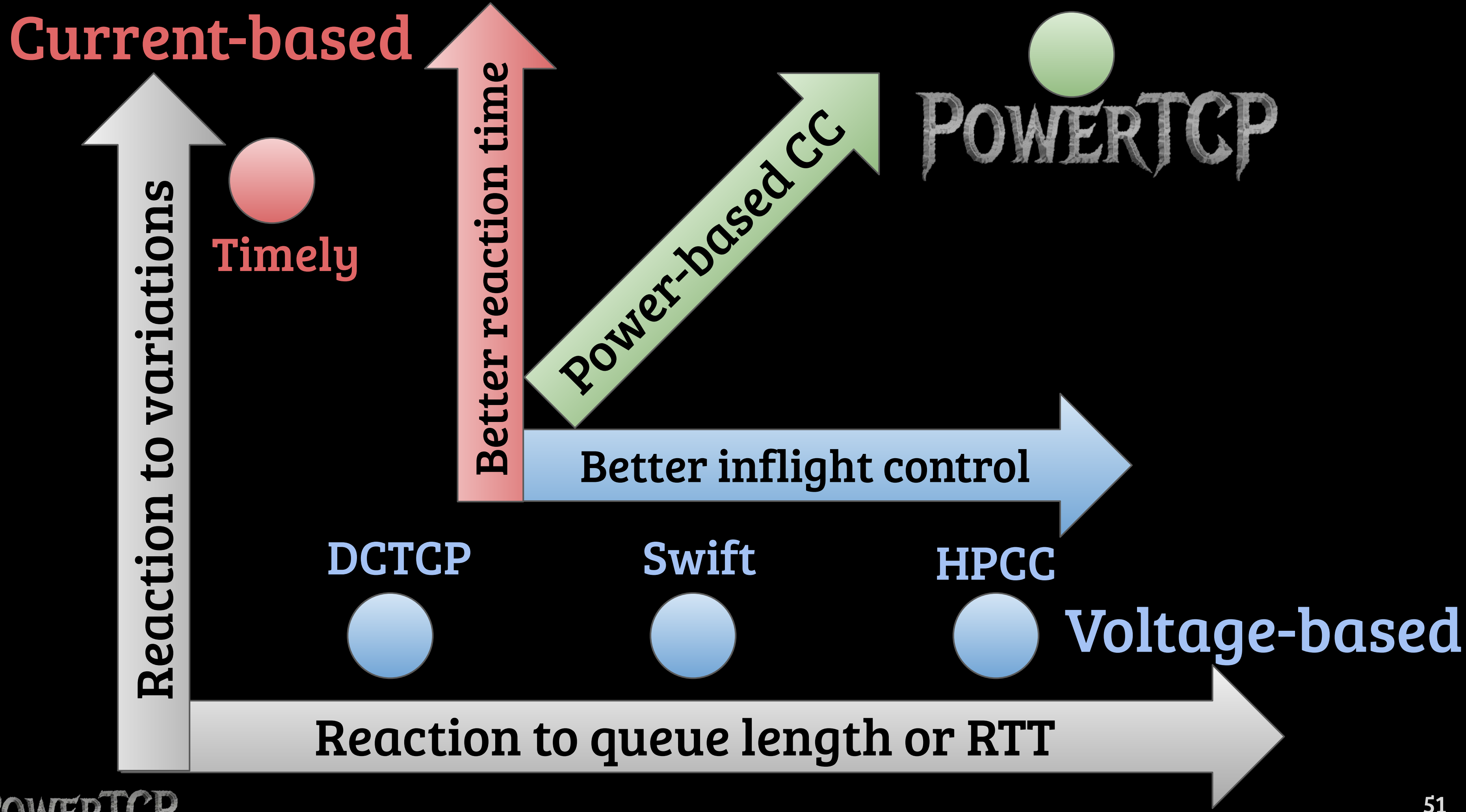
DCTCP

Swift

HPCC

Voltage-based

Reaction to queue length or RTT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Timely
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PowerTCP control law

$$\boxed{w_i(t+\delta t)} = \gamma \cdot \left(w_i(t) \cdot \tfrac{e}{f(t)} + \beta \right) + (1-\gamma) \cdot w_i(t)$$

New window size

PowerTCP control law

$$w_i(t+\delta t) = \gamma \cdot \left(\boxed{w_i(t)} \cdot \frac{e}{f(t)} + \beta \right) + (1-\gamma) \cdot w_i(t)$$

$\downarrow$

Old window size

PowerTCP control law

$$w_i(t+\delta t) = \gamma \cdot \left(w_i(t) \cdot \boxed{\frac{e}{f(t)}} + \beta \right) + (1-\gamma) \cdot w_i(t)$$

MIMD based on Power

(Multiplicative increase - multiplicative decrease)

PowerTCP control law

$$w_i(t+\delta t) = \gamma \cdot \left(w_i(t) \cdot \frac{e}{f(t)} + \boxed{\beta} \right) + (1-\gamma) \cdot w_i(t)$$

↓

Additive increase

PowerTCP control law

$$w_i(t+\delta t) = \boxed{\gamma \cdot} \left(w_i(t) \cdot \frac{e}{f(t)} + \beta \right) + \boxed{(1-\gamma)} \cdot w_i(t)$$

Exponential Weighted Moving Average (EWMA)

PowerTCP feedback

Power is measured via Inband Network Telemetry (INT)

- Queue lengths
- Timestamps
- Tx bytes
- Bandwidth

PowerTCP without switch support

- Power can be measured via delay signal

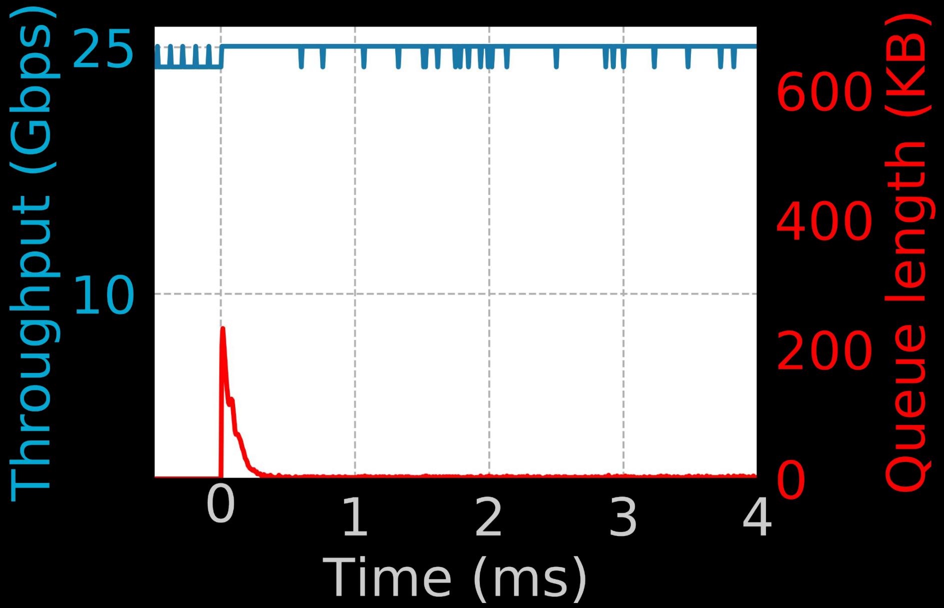
PowerTCP without switch support

- Power can be measured via delay signal

$$\underbrace{\Gamma}_{\text{Power}} = b^2 \times \underbrace{\theta}_{\substack{\text{Voltage}\\ \big\downarrow \\ \text{RTT}}} \times \underbrace{(\dot{\theta} + 1)}_{\substack{\text{Current}\\ \big\downarrow \\ \text{RTT gradient}}}$$

Evaluation

Evaluation - Incast



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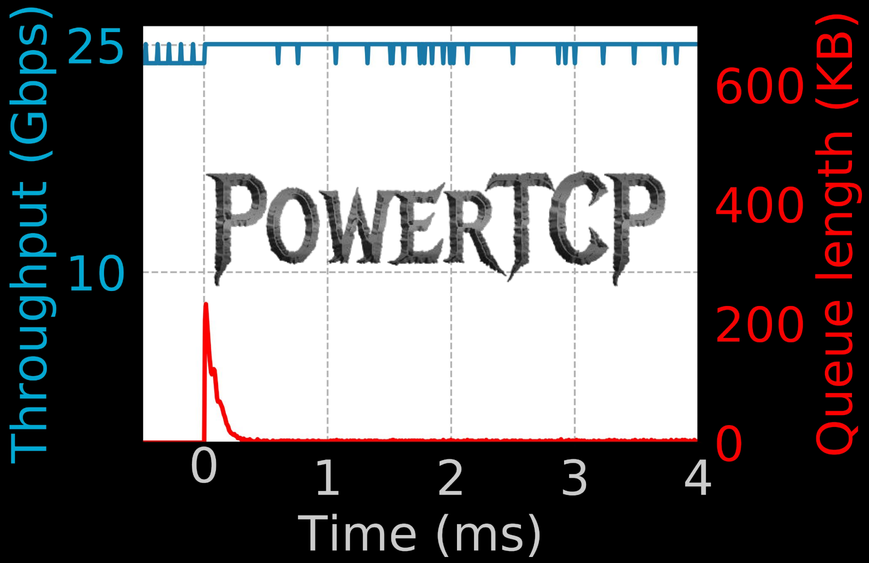

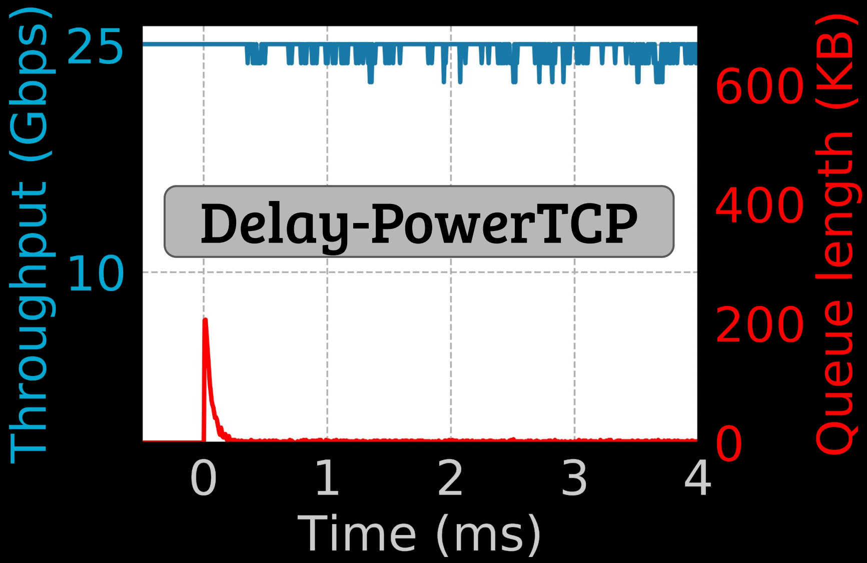

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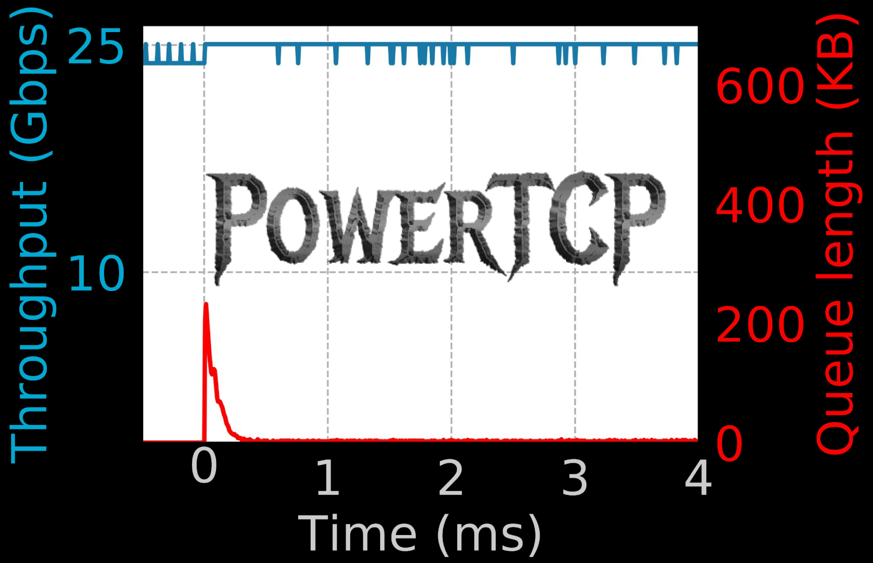

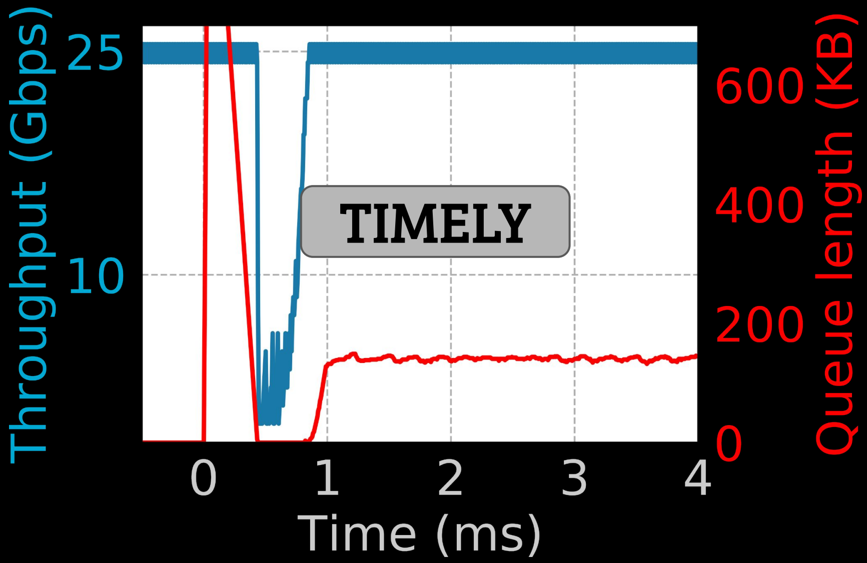

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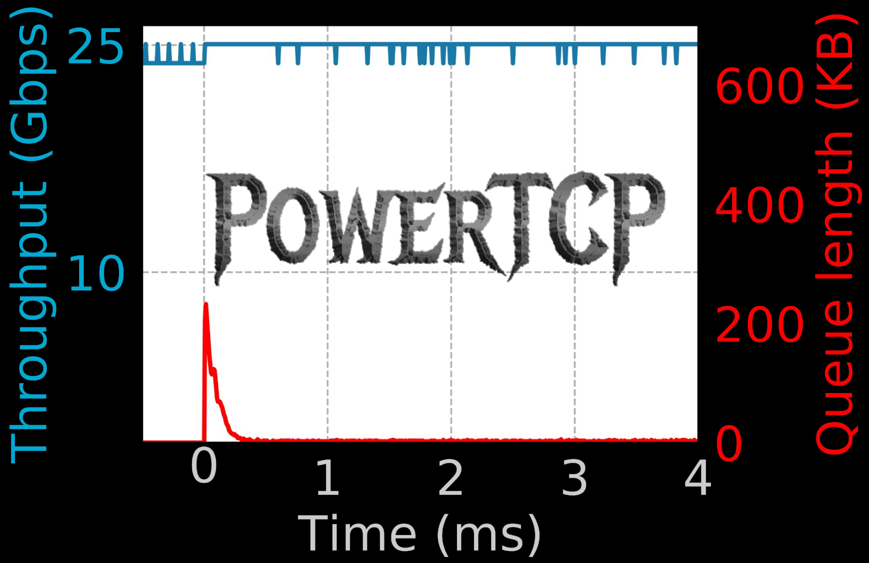

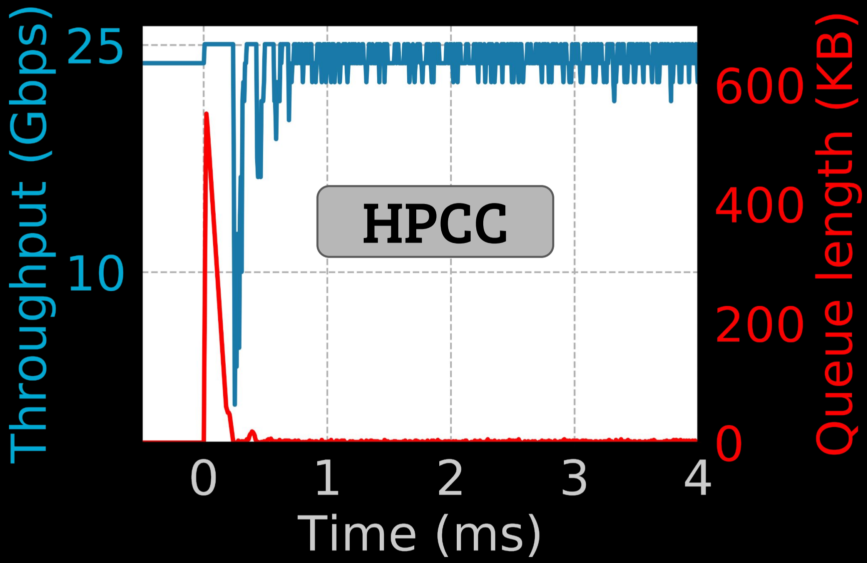

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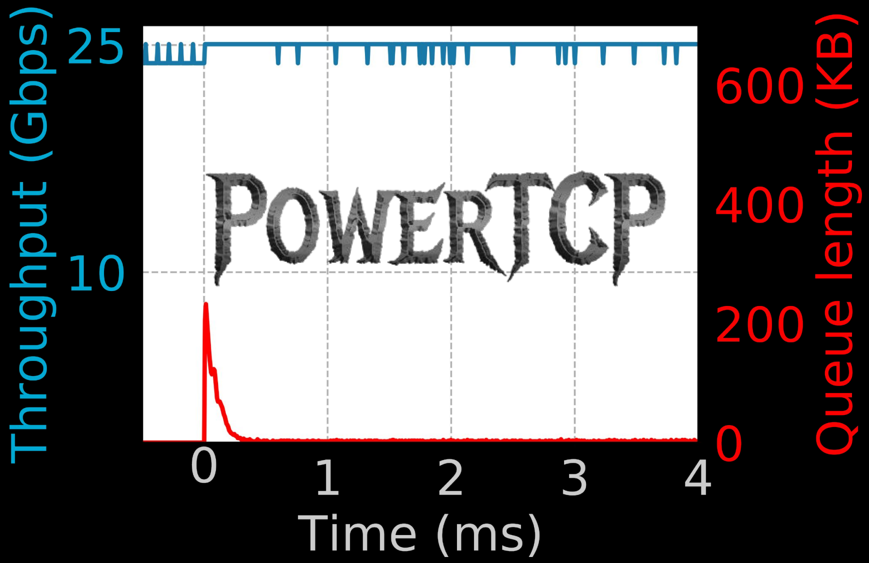
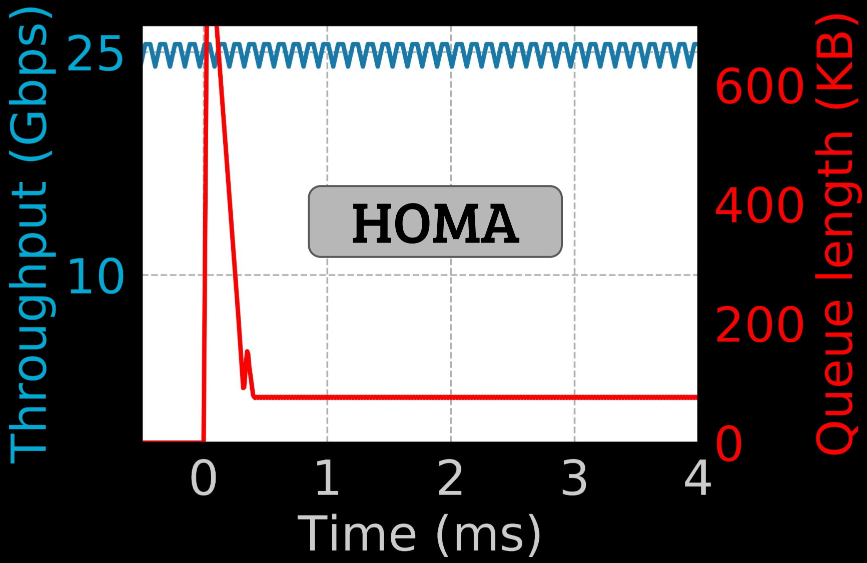
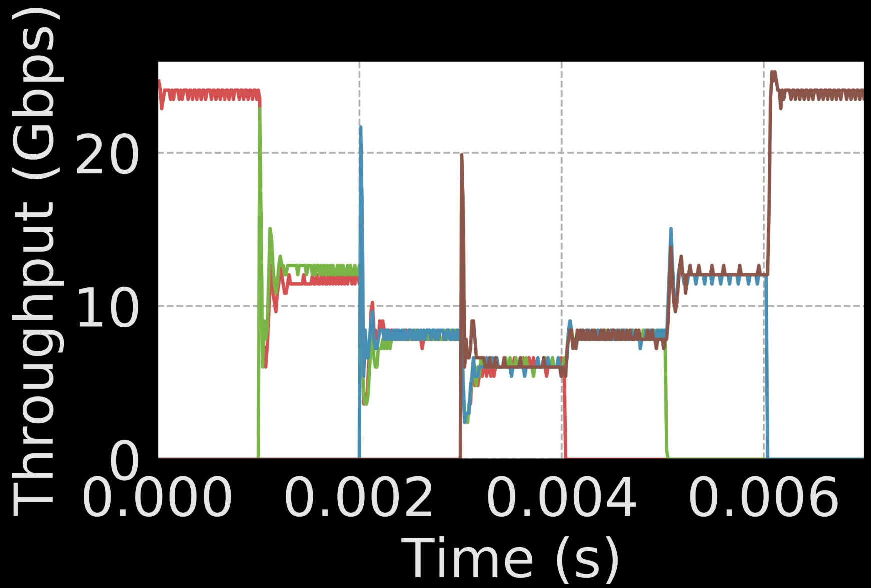




Evaluation - Fairness & Stability



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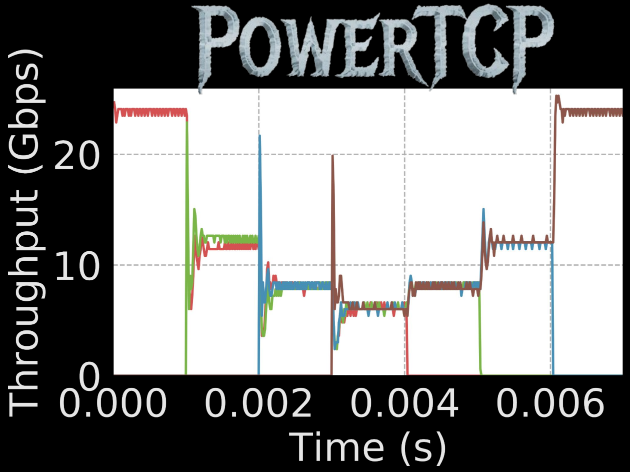
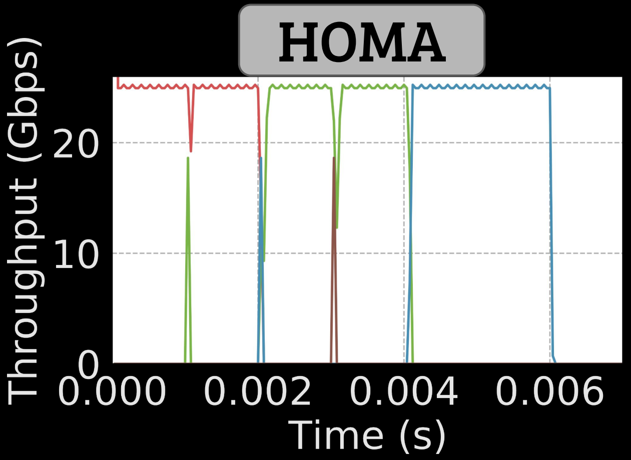
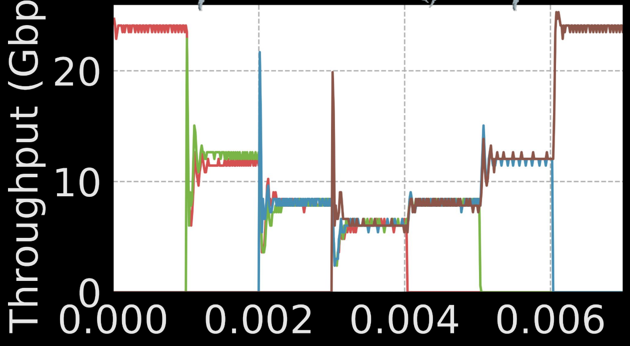


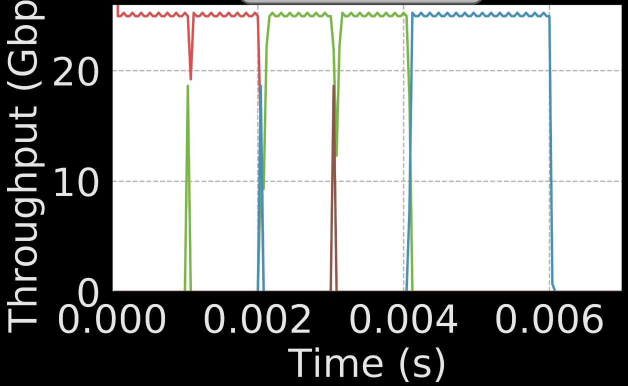


Evaluation - Fairness & Stability

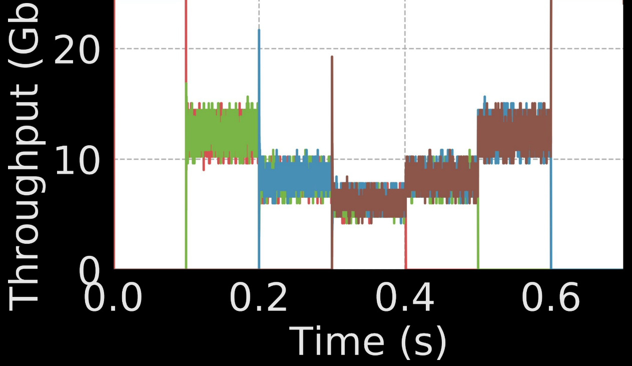
PowerTCP



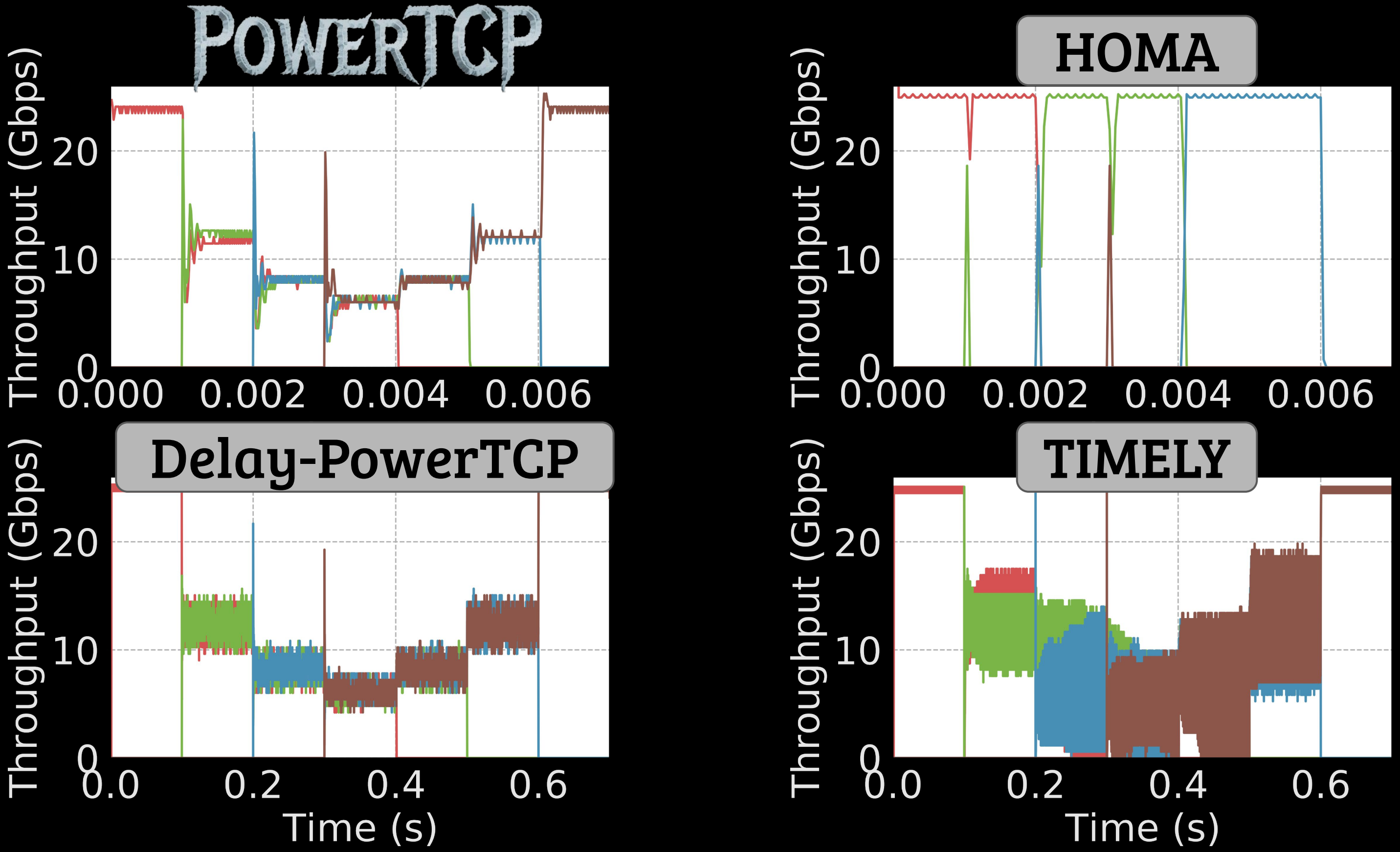
HOMA



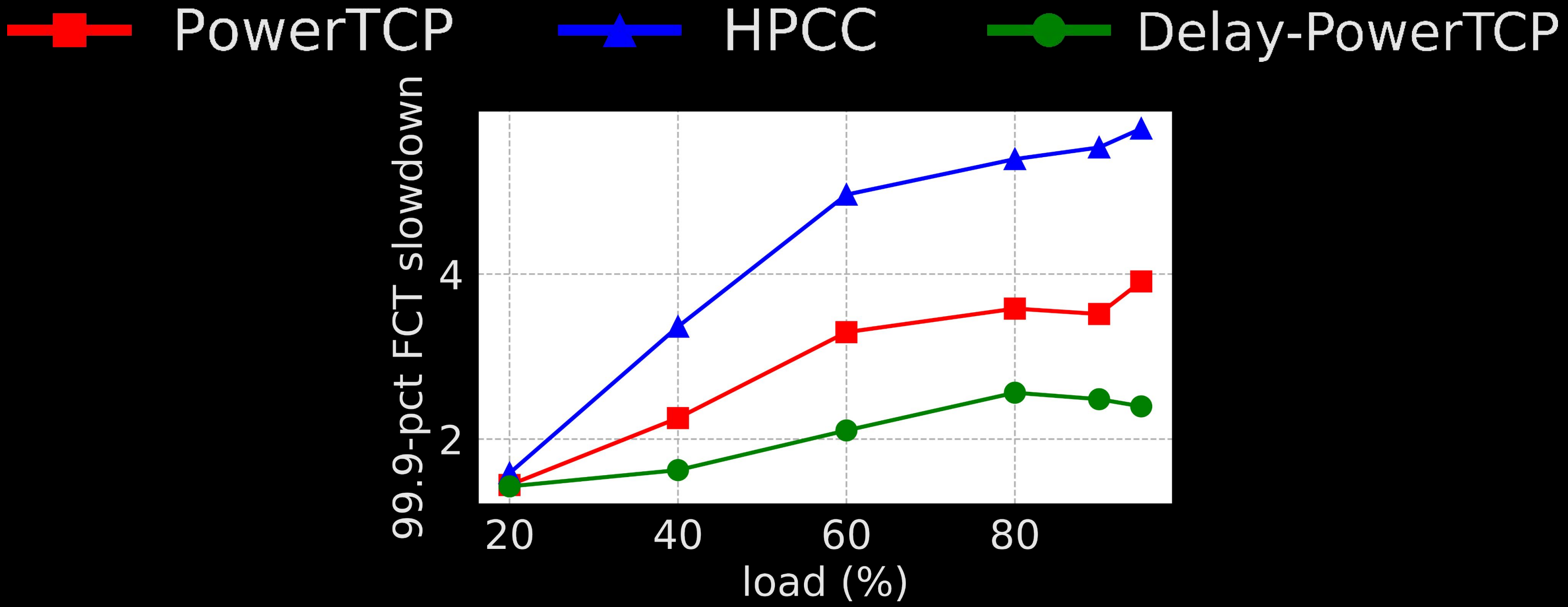
Delay-PowerTCP



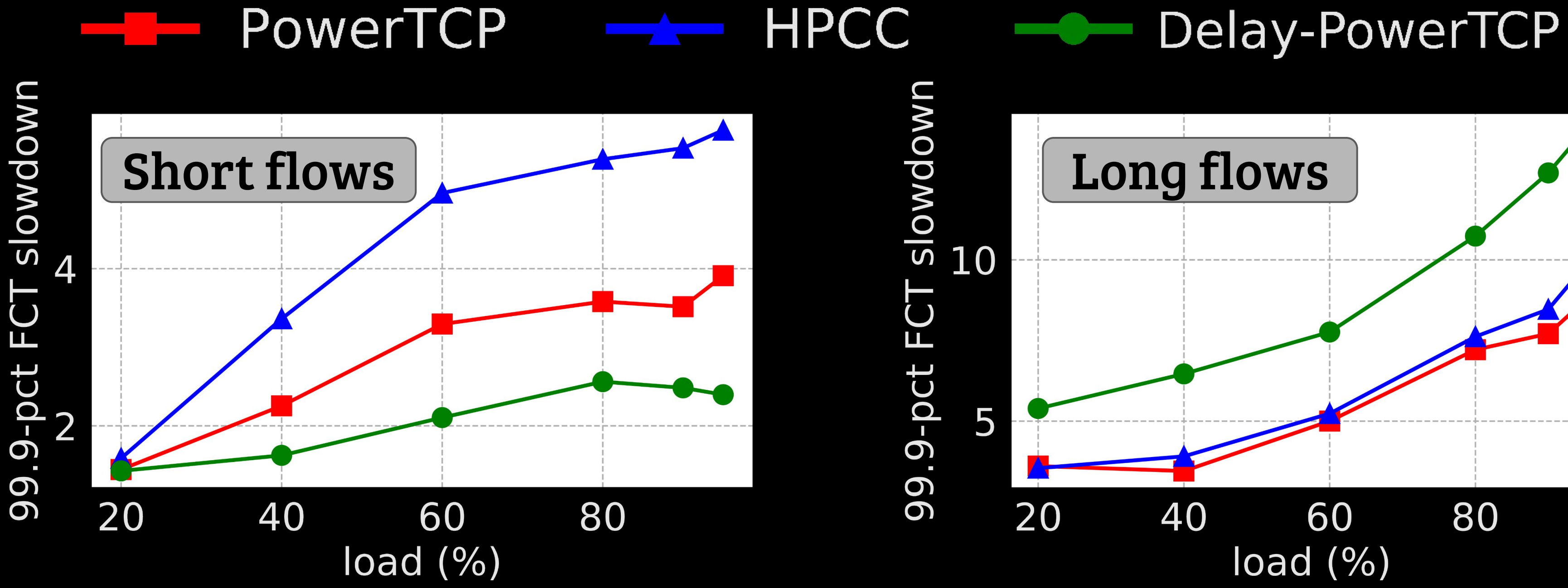
Evaluation - Fairness & Stability



Evaluation - Workload

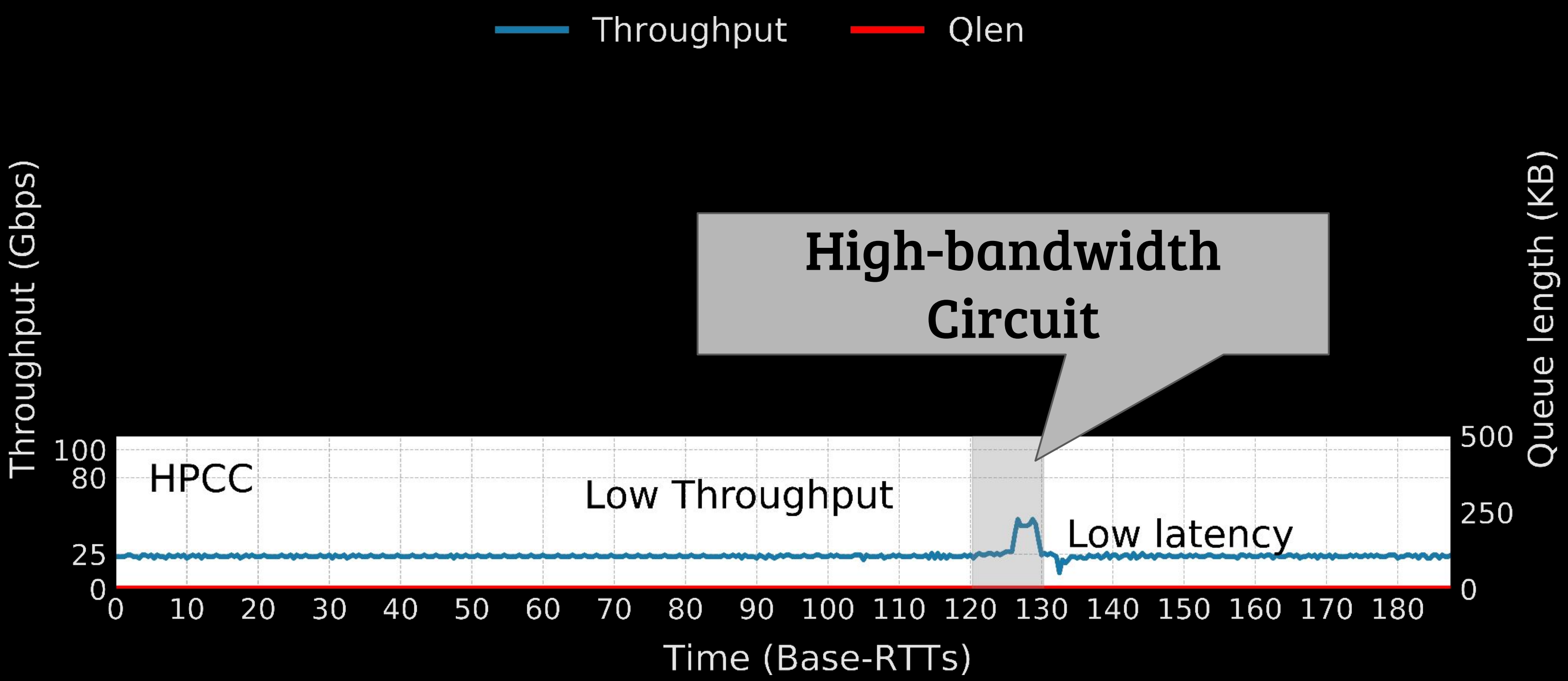


Evaluation - Workload



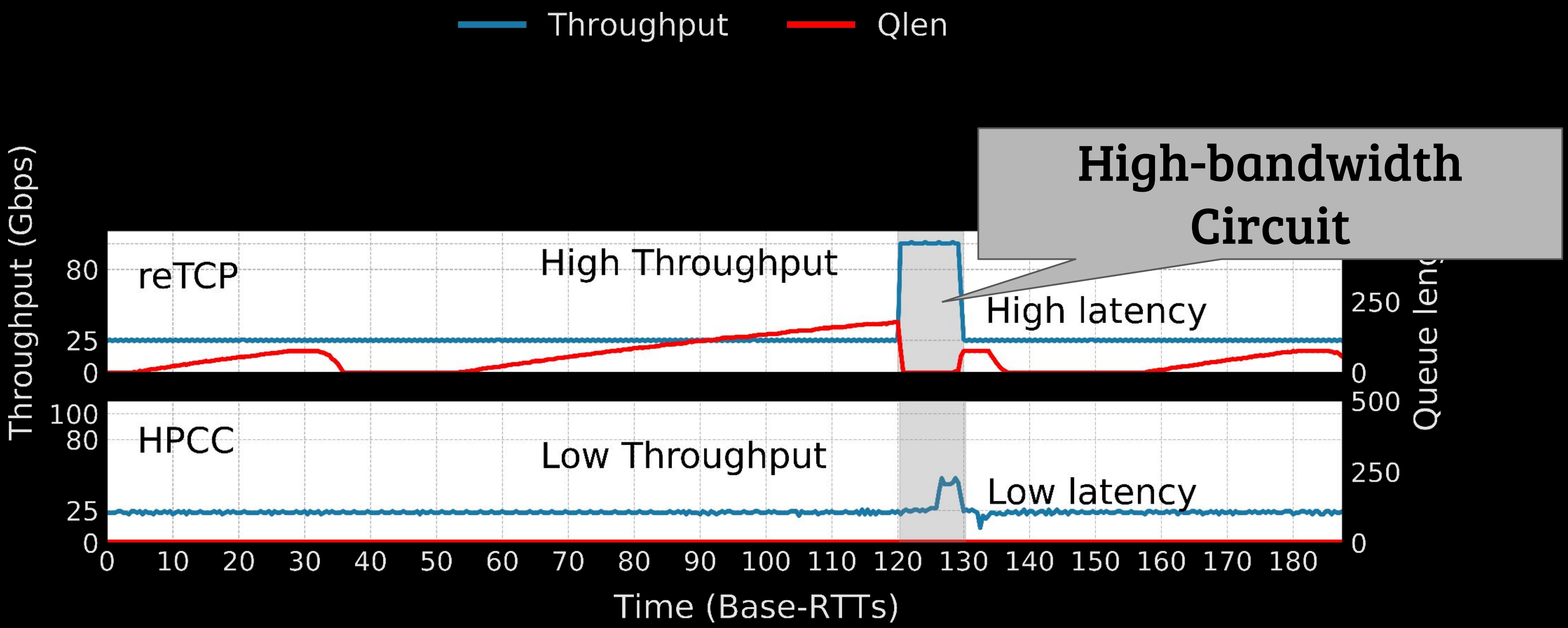
POWERTCP

Evaluation - Reconfigurable Networks



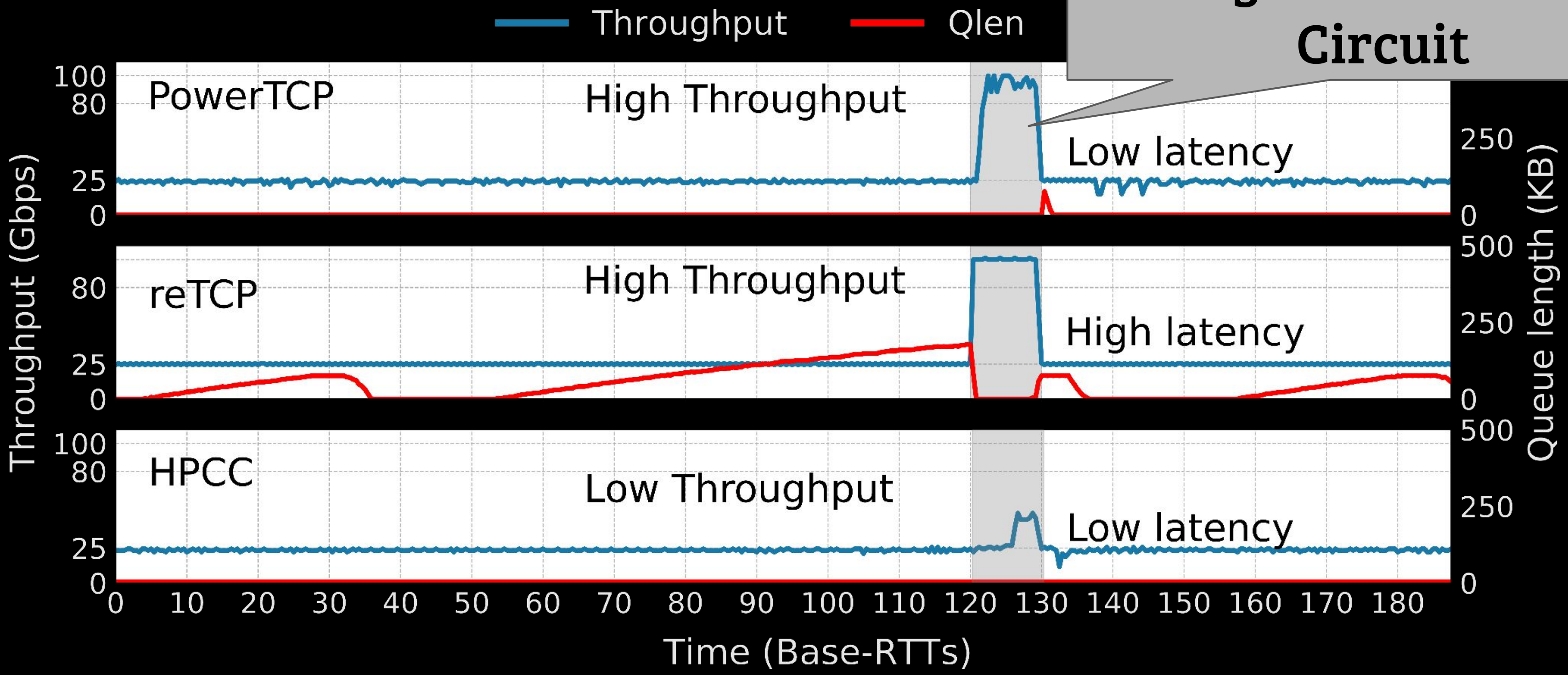
High-bandwidth Circuit

Evaluation - Reconfigurable Networks



High-bandwidth Circuit

Evaluation - Reconfigurable Networks



High-bandwidth Circuit

Conclusion

- Existing CC are fundamentally limited to a single dimension
- Power is an interesting and provably good measure for CC
- PowerTCP: a novel control law based on Power
- Improves FCTs for short flows and even for long flows

Thank you